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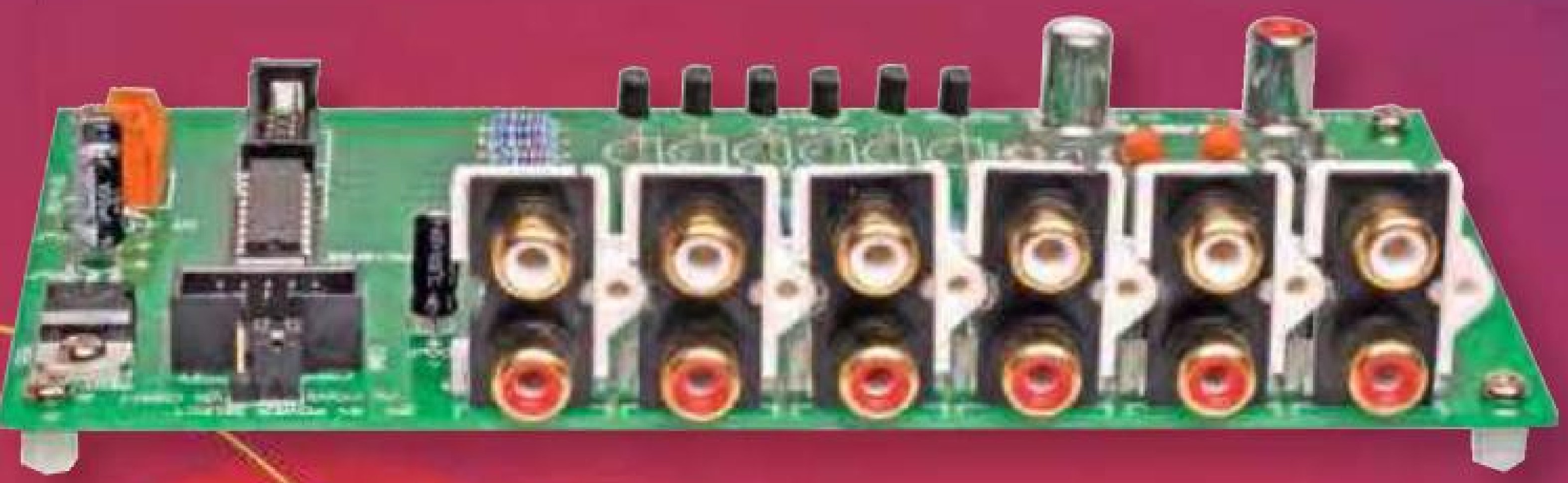

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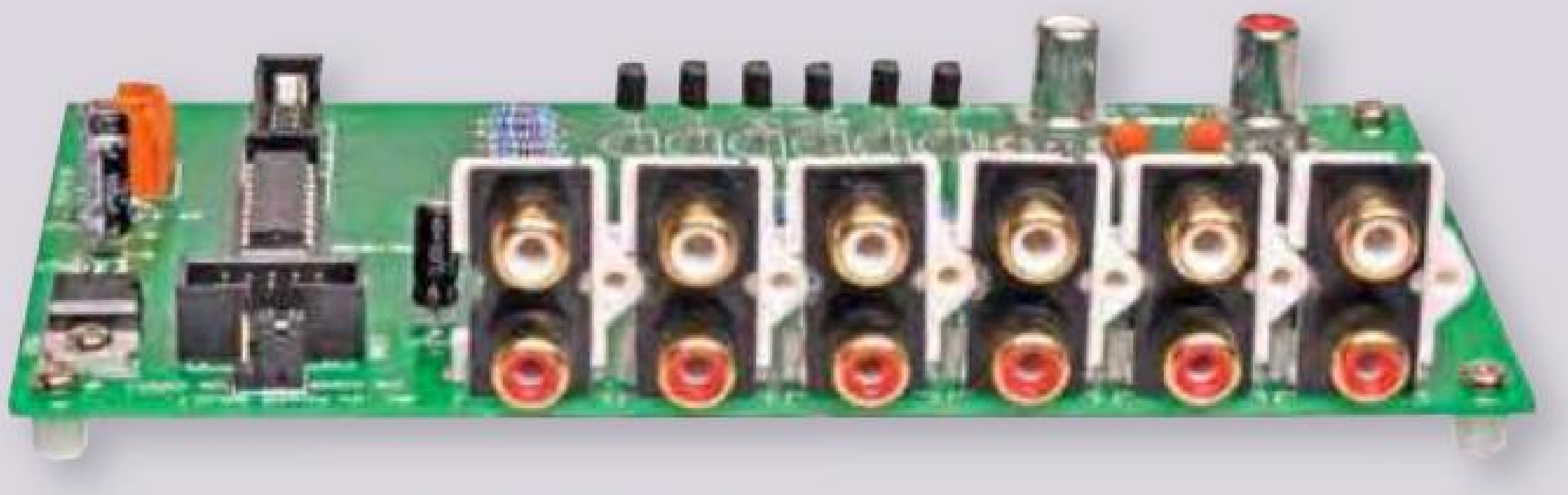

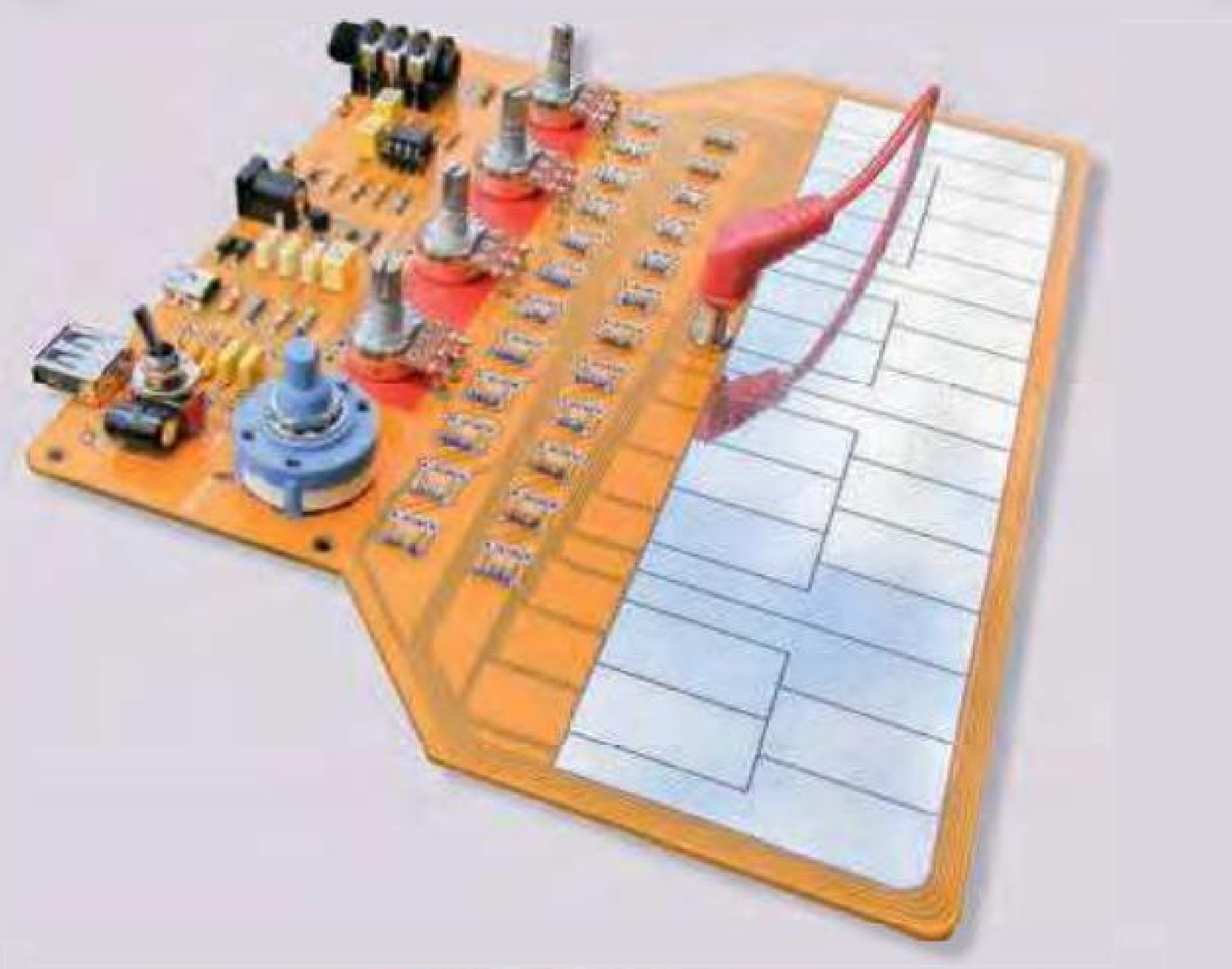

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The July 2020 issue of *Practical Electronics* will be published on Thursday, 4 June 2020 – see page 72.

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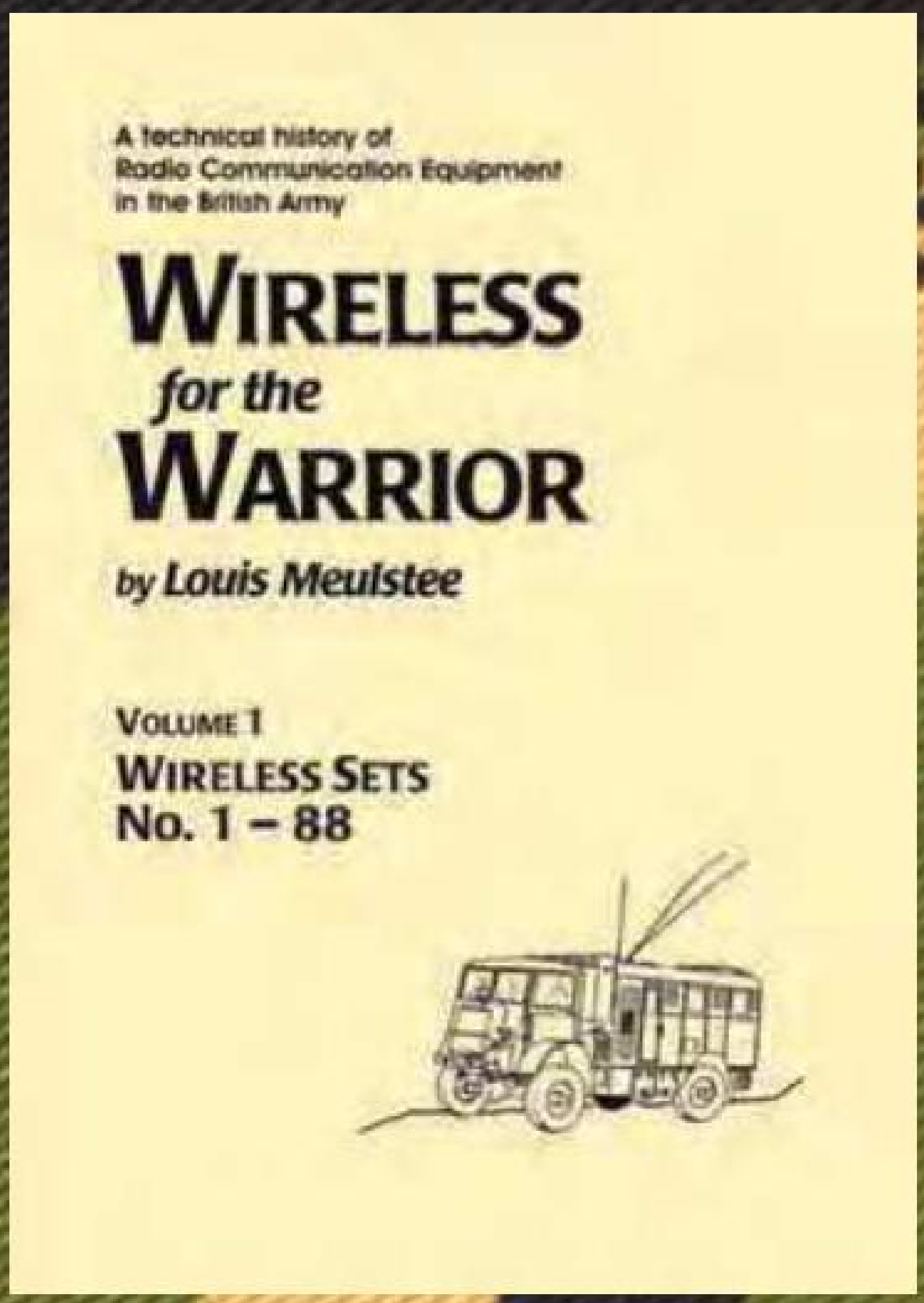
Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.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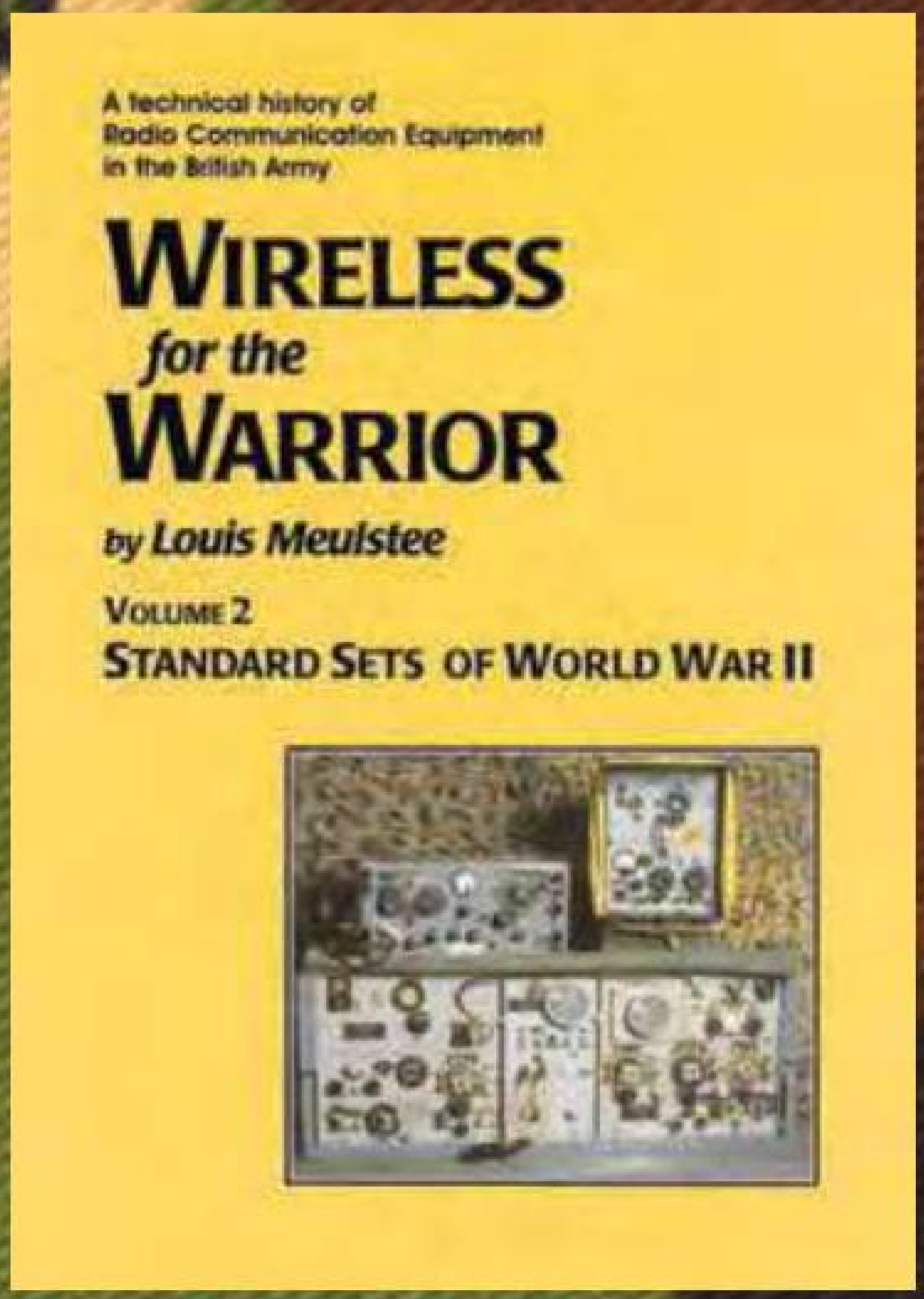
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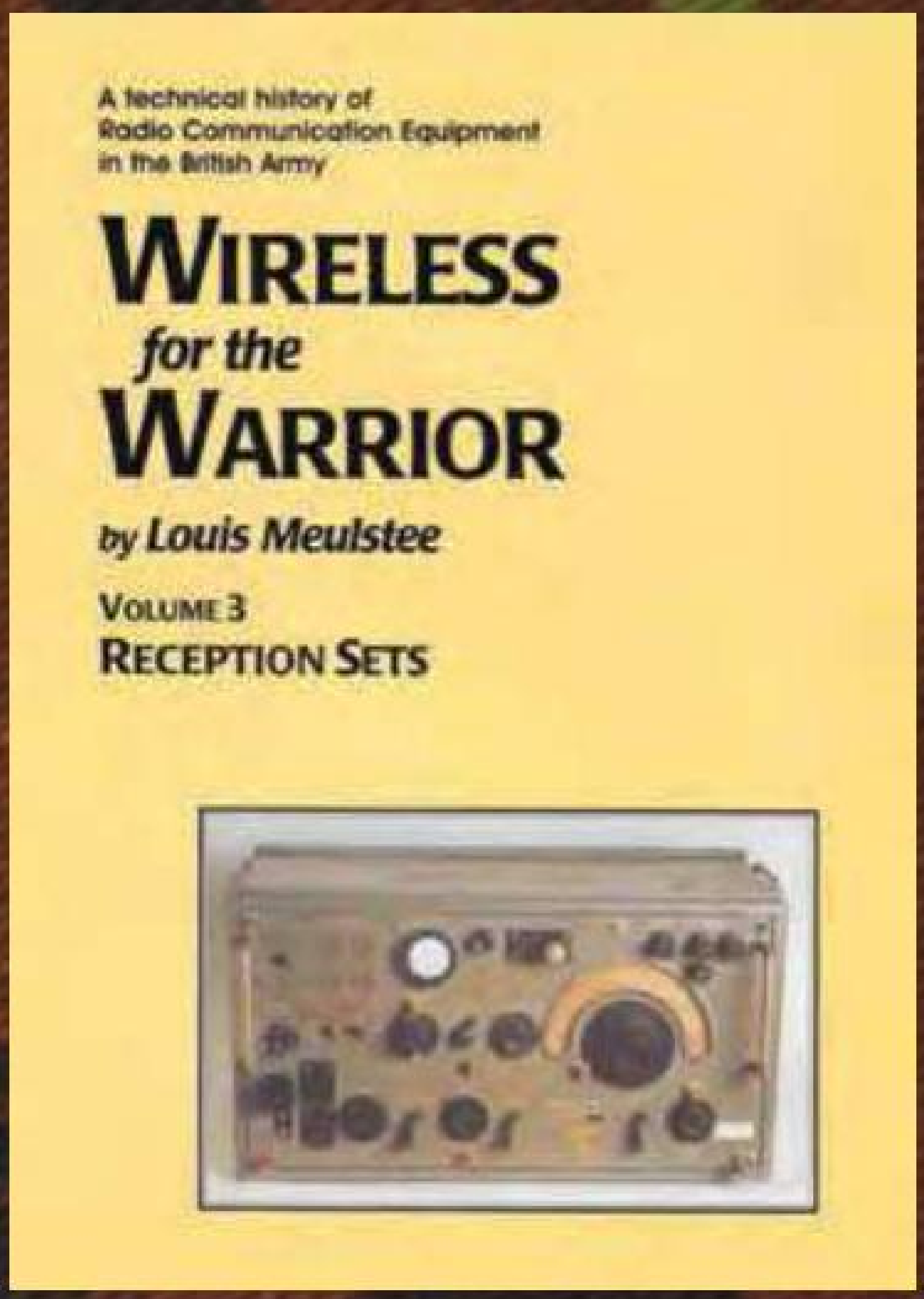
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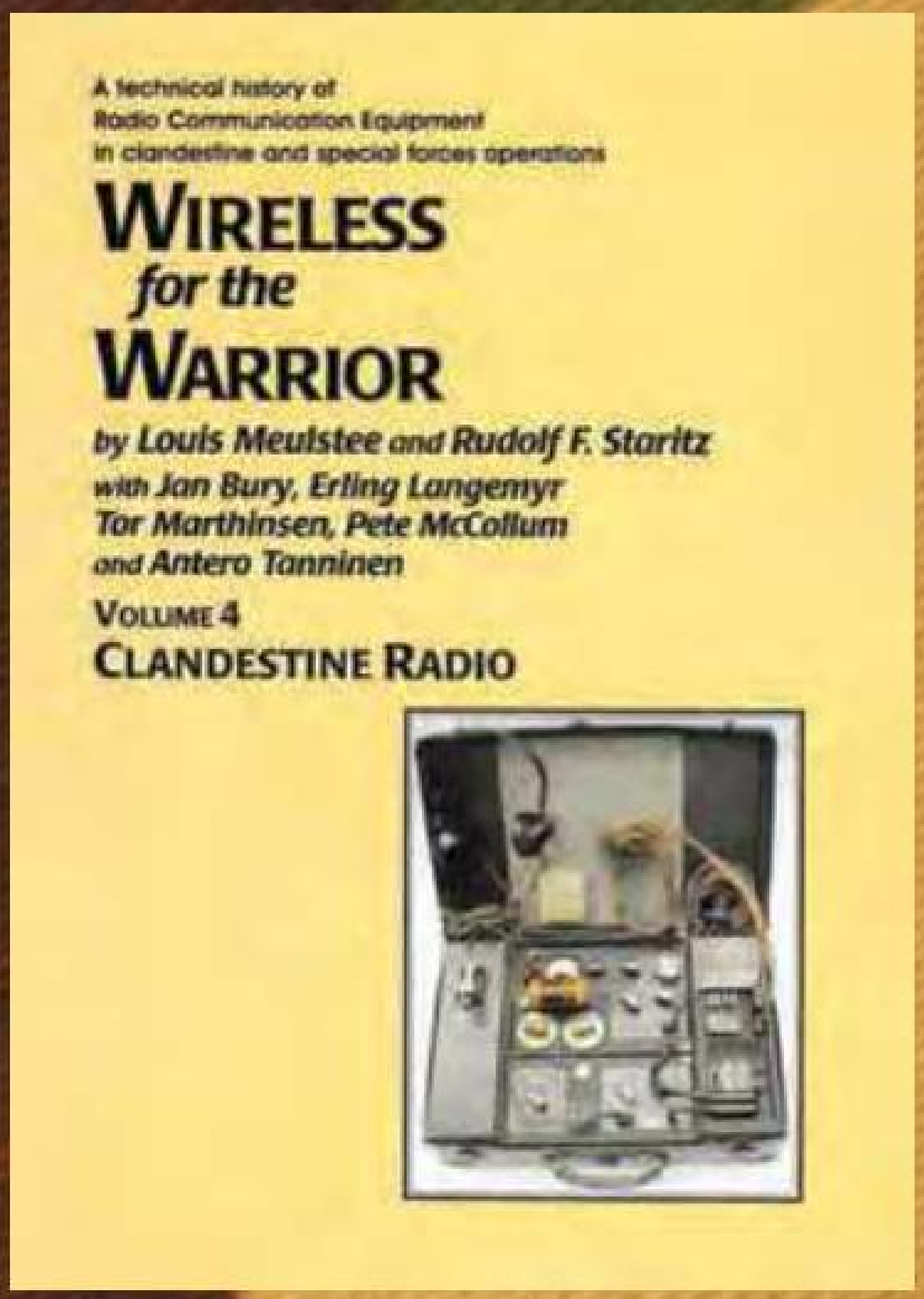
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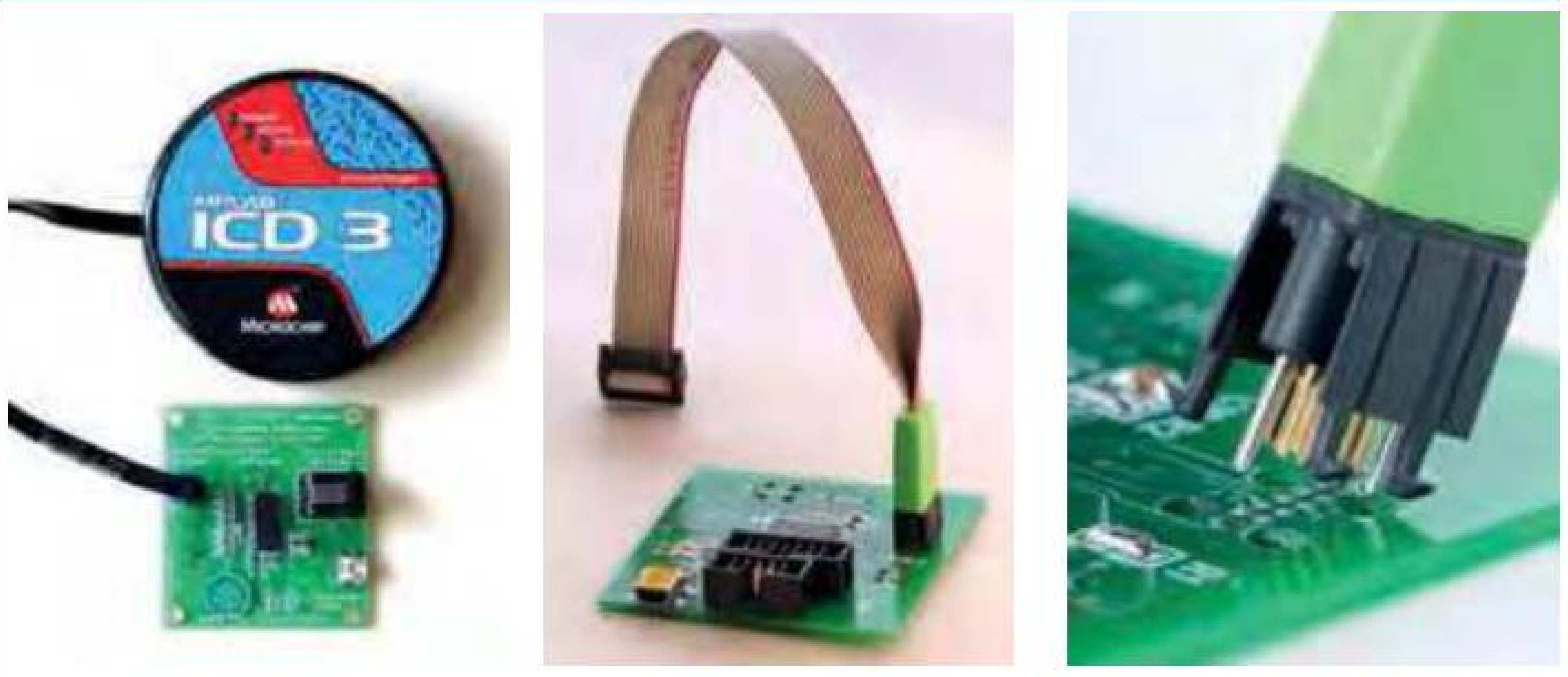

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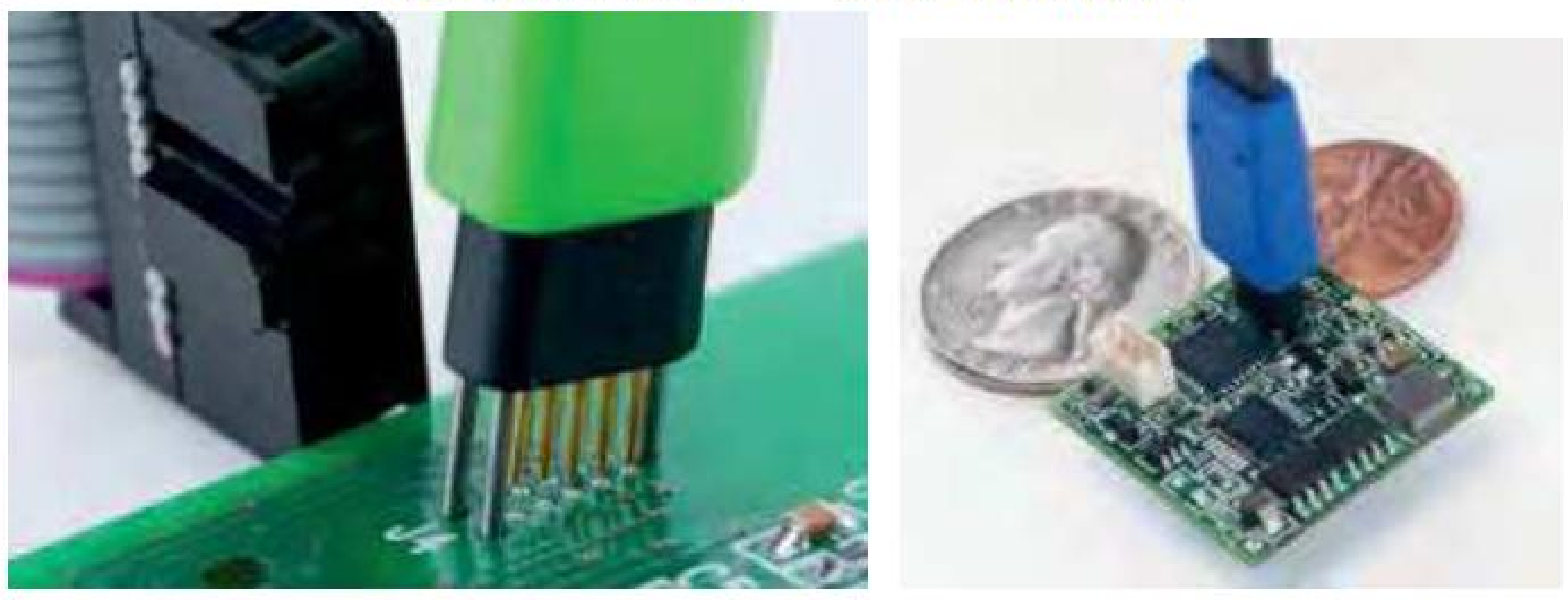

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These are exceptional times, and coronavirus is changing how everyone lives and works. Here at Electron Publishing we are working hard to ensure there is as little disruption as possible to the production and distribution of *Practical Electronics*.

Unfortunately, however, some delays in delivering your magazine are inevitable – here is a rough guide to the situation in late April.

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If you subscribe to *PE* in the UK then we expect little delay or interruption to the delivery of your magazine.

For non-subscription readers in the UK, we sell most of our copies through WHSmith and a few other outlets such as supermarkets and independent newsagents. At present, we expect many of them to stay open and receive *PE* as before, but we do not control this and hence cannot offer the same reassurance of availability that subscribers enjoy. However, if your local supplier is shut or you simply want to minimise shopping and maximise social distancing then you can buy it from our online store for exactly the same price – *we’ll pay the postage and deliver it to your door*.

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Actually, that’s not quite true. We will soon be launching a new digital subscriber system for PDF downloads, but this is nothing to do with the current health emergency, and is part of the overall rebuilding of *PE’s* online presence.

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Practical Electronics

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Keep calm and solder on!

These are strange and unnerving times, but we have to make the best of it. Doubtless, each of you has your own coping mechanisms for staying sane, and I hope *PE* is playing a small part in helping you pass the time productively. Electronics is a great way to engage the brain and keep occupied.

With that in mind, I'm grateful to reader Alan Macdonald for pointing out that last year we carried the perfect project for the current situation – I mean of course Jake Rothman's *Theremin*. As Alan quipped in an email exchange with me when discussing the project – 'it seems like a good way of spending time during lockdown, with the added bonus that since you don't touch it, you don't have to clean it!'

This issue

As always, we have something for everyone in this month's magazine. From an *RF Signal Generator* for radio enthusiasts to a *Mini-organ* for the musically inclined, I'm sure you'll find material that will keep you inspired and entertained. I particularly enjoyed Ian Bell's explanation of class-D, G and H amplifiers, and Phil Boyce's *Micromite Robot Buggy* is just the kind of original project that makes *PE* special. Read on and enjoy!

The PE PCB & PIC Service

I was hoping for a loud fanfare of trumpets for our new PIC service – but so far it is quite a modest affair, so I'll settle for a quieter announcement. The good news is that it is up and running, and if you want a programmed PIC for a project that has appeared in *PE* then look for it in our online shop in the PCB section – soon to be renamed the *PE PCB & PIC Service*. Not all possible PICs are available yet. Those that are, sit alongside the relevant PCB for a particular project, arranged by issue month and year. At first, we will stick to the most common PICs – all DIP packages – and then slowly expand to cover other devices and package types.

Thank you!

Last, I would like to thank the many businesses that are working hard with us in very difficult circumstances. Quite simply, without them you would not be able to read these words. *PE* is very fortunate to have great support from our printer (Acorn Web), distributor (Select Publishing Services), partner magazine in Australia (*Silicon Chip*) and the numerous postal services in the UK and around the world that have helped keep our magazine going – thank you one and all.

Keep well everyone

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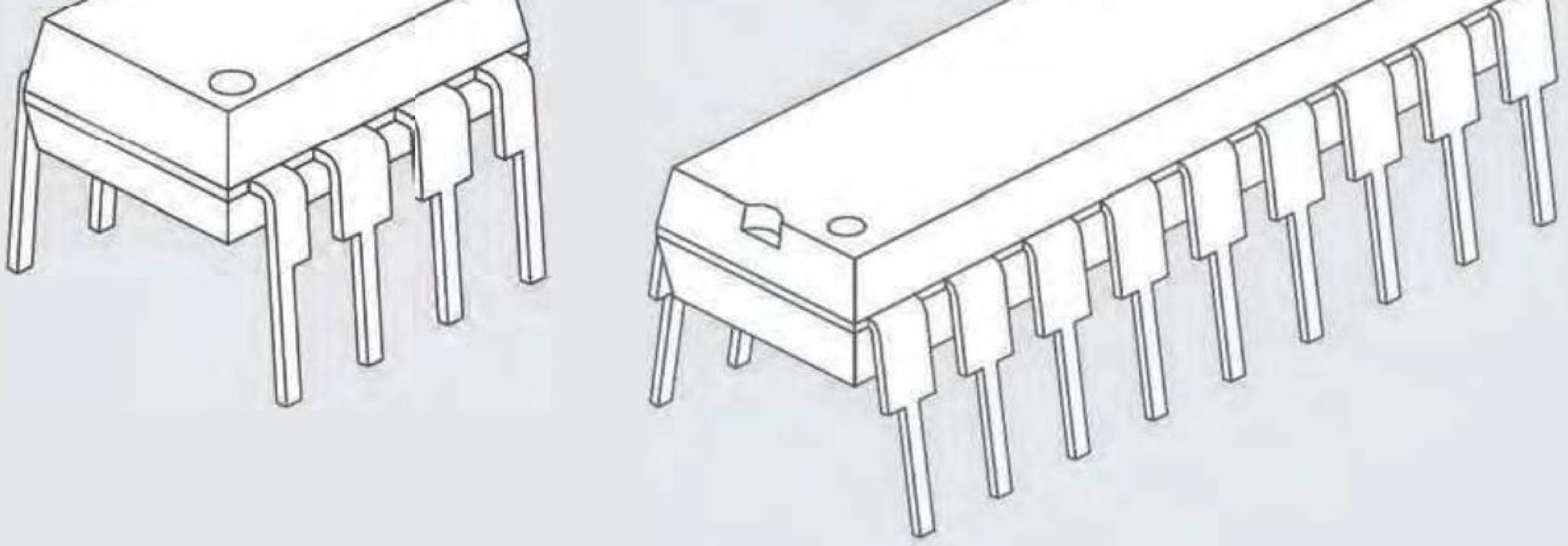

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Beyond back-of-the-envelope design

Techno Talk

Mark Nelson

It's in our genes. Some of us are innately attracted to pictures of cute kittens. Others cannot resist buying new gadgets for their electronics man cave or lady cave or... no, I mustn't get side tracked! But don't worry; buying clever new products doesn't make you a bad person. Far from it – your brain absorbs some of the intelligence of the smart kiddos who came up with these new ideas. Buying them aids the economy and heaven knows, we can do with that.

So own up now; are you a gadget freak like me? No? Then you are exempted from reading any more of this exuberance. Yes? Then *keep calm and carry on!* Even though I consider myself a fairly seasoned electronicist, I still cannot resist trying new products, especially when they appear to save both time and money. I also cannot resist spreading the word when I discover something new that might interest you as well. In this case, it's a product that was 'new' in 2012, so it's not technically a novelty, but even so, it might still be new to you, so no harm done.

Ancient and modern

First, we need a bit of history to put this innovation in context. Back in the Dark Ages, even if the Venerable Bede did not specifically mention it, we know that people designed electronic circuits on the back of envelopes. When they were certain that their creation had a fair chance of working, they knocked up its physical realisation on perfboard – a kind of resin-bonded-paper material, drilled with loads of little holes in parallel rows. You can still buy perfboard, although it's now provided with solderable circles around each hole to anchor the leads of inserted components.

Back in the 1950s and 60s, however, the primitive perfboard sold then had no such solder-friendly luxuries. Instead, you placed the leads of your resistors, capacitors and other components into a hole and soldered them below the board with a big gob of solder. Next, you applied power to your new creation, and then found that it didn't work.

The arrival of Veroboard (also known as stripboard) made making prototype circuits much easier, by adding parallel copper tracks to perfboard. Components could now be connected by these tracks, which could be isolated by using a hand-held 'spot face cutter' to interrupt a track at one of the holes and form separate electrical nodes. Cheapskates used a drill bit in a pin chuck, but this often weakened the board.

It was Terry Fitzpatrick who had the brainwave for this revolutionary product; and the patent application was made in 1959 under the name of his employer , Vero Precision Engineering Ltd. Geoffrey Verdon-Roe was the managing director of this enterprising company and now you can guess why he called it 'Vero'.

Veroboard was undoubtedly a major breakthrough, but many of the designs made on it still didn't work first time around. The components that you soldered into place (and trimmed off the leads) were still either difficult or impossible to reuse. There had to be a better way.

Step change

The revolution arrived around 1970 with the solderless breadboard, a specially perforated block of plastic in which an array of tiny metal spring clips below the holes could hold and retain the leads of components, jumper wires and other items. Instead of soldering components, you now simply pressed them into place, with the ability to 'unplug' them when things inevitably didn't work. Now you could rearrange them at will, redesigning the circuit until it jolly well did work.

One of the first breadboards in Britain was called 'S-DeC', leading to arguments in electronic labs over whether it should be called an 'ess-deck' or an 'ess-dee-cee' (I never found out which pronunciation was correct). The Verobloc was a similar product and what all of these offerings had in common was a fearsome price. From memory, they cost about £20 in the early 1970s, equivalent to £266 in today's money, so it's little wonder that they were beyond the reach of the average hobbyist. Today, you can buy them for under £1, although that money will secure only a cheaply made example.

Getting to the point

Having used the breadboard to confirm that your circuit now works, you need to make a couple of prototypes for evaluation. The easiest way would be to use a PCB that mimicked the exact size and metrics of the breadboard that you used. And that's precisely what the Perma-Proto Board does (**www.adafruit.com/product/1609**). It comes in three sizes (full, half and quarter) and the plated-through holes are in never-tarnish gold. According to Adafruit, the white silkscreen on the upper side has the same breadboard markings you're familiar with, helping to make transferring components easy. The underside has the five-hole pad design that matches a classic breadboard, with four power bus lines on the sides, and no mask so you can easily cut tracks when necessary. The drill holes used are of 1.2mm diameter, so even parts with larger leads will fit. For photos showing how to use the boards, see: **https://bit.ly/pe-jun20-ada**

Tempted to try one out? Why not? These boards are available from several mainline distributors such as Farnell/Element14 and are frequently cheaper on Amazon and eBay. But beware when comparing prices; these clever gizmos come in packs of three but some sellers are splitting the packs to make them look cheaper!

And I do concede that unlike the breadboards that they emulate, they are not cheap. Yes, good value for what they are, but not cheap. You can of course help yourself by optimising your breadboard layout and squeezing the components as close together as you can. By doing this, you may be able to squash your proof-of-concept circuitry onto a half or quarter-size Perma-Proto board, saving cost. Even better, as your skills improve, maybe your designs will work the first time around, making faffing around with breadboards and proto boards unnecessary. After that, all you will need is more backs of envelopes!

Net Work

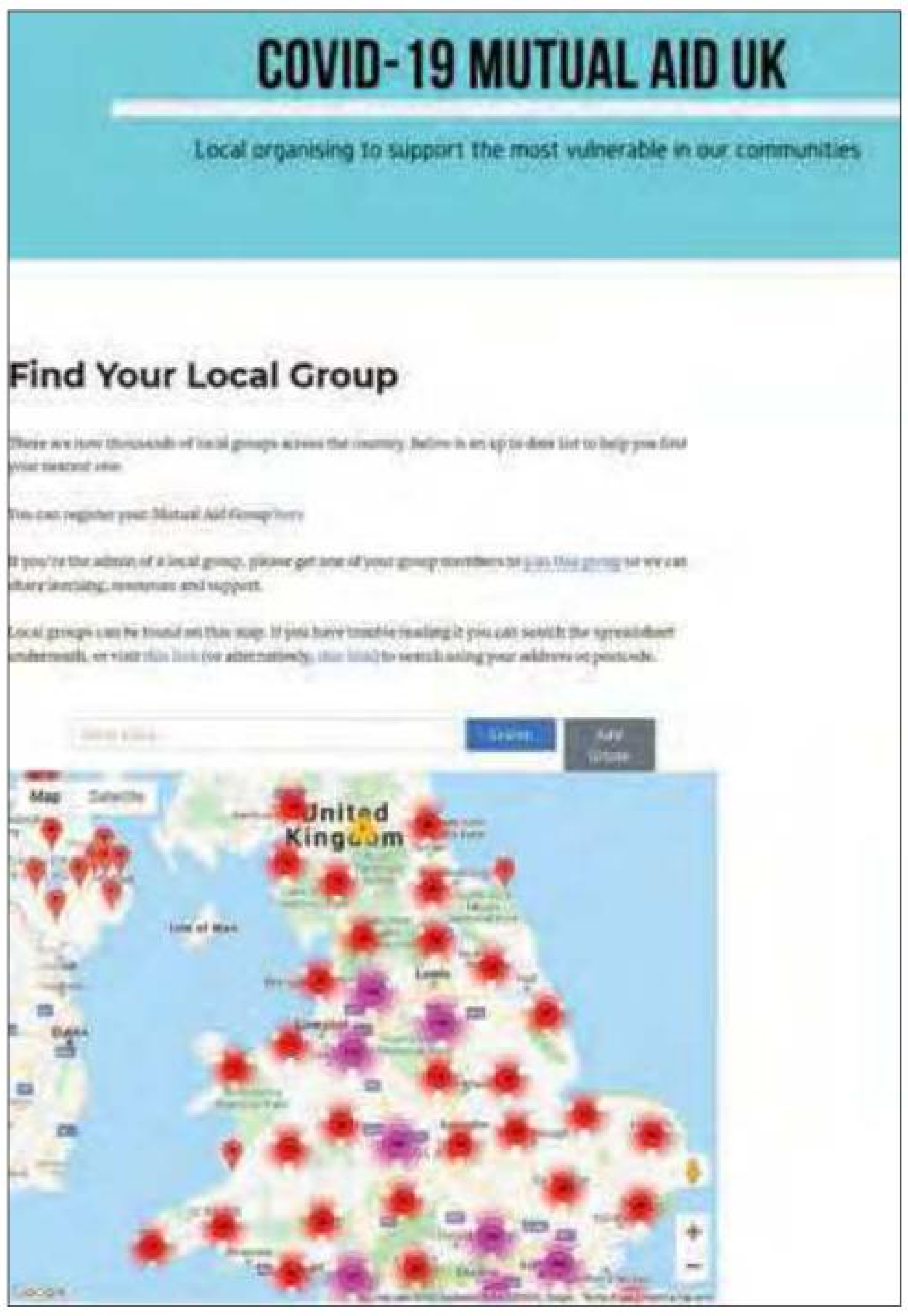
Alan Winstanley

In an era of lockdown and social distancing the Internet is more important than ever. This month, *Net Work* looks at apps, security and some pleasingly welcome diversions.

Welcome to this month's *Net Work*, the column dedicated to home network and Internet users. Currently banished from setting foot outdoors, the majority of households seem to have migrated online, so much so that streaming services including Netflix and Amazon Prime have reverted to broadcasting in standard definition to save bandwidth, and the streaming of sports fixtures on BT and Sky Sports have also been curtailed (not helped by the English and Scottish Premier Leagues being suspended anyway).

During lockdown, the Internet has saved the day for many, and legions of local communities have busily organised themselves into online mutual aid groups dedicated to helping with pharmacies, shopping errands and similar tasks. The remarkable endeavours of many public-spirited people are bringing out the best in communities; in Britain, details of these groups can be found on **https://covidmutualaid.org** or search Facebook locally for your nearest Covid-19 Mutual Aid Group.

Readers at home and overseas might also be interested in the UK's National Health Service (NHS) website at: **www.nhs.uk** which is both authoritative and refreshingly advertisement-free; its 'Health A-Z' directory explains a vast range of medical conditions and is often a good starting point for further research, though it tends to be overly cautious with its advice.



COVID-19 MUTUAL AID UK

Local organising to support the most vulnerable in our communities

Find Your Local Group

Covid-19 Mutual Aid Groups have sprung up everywhere in the UK – search the map to find your nearest one.

Social media to the rescue

Social media came of age during the trendy era dubbed 'Web 2.0', and in recent weeks the web has hosted countless Whatsapp chats and live streaming events to help keep everyone's spirits up. Everything from live quizzes to online disco parties, free games and much more besides will be found online during these challenging times. Whatsapp sessions are encrypted from end to end (which cannot be disabled) and for virtual get-togethers, the Houseparty social network app, a simple face-to-face video chat service now owned by Epic Games of *Fortnite* fame, has become all the rage. Houseparty handles live, unmoderated video feeds and Houseparty users should be sure to lock their virtual room to avoid gatecrashers. As Houseparty is very popular with younger users, more safeguarding advice (especially for parents) is on the UKs Internet Matters website at **https://tinyurl.com/v3chsq9**. You can download Houseparty from Google Play or the App Store. (Bad news for Firefox users: on a PC desktop it only works in Google Chrome.)

The main alternative to Houseparty that's caught on recently is the video conferencing suite Zoom, which is aimed more at the business, health-care and professional sectors. Zoom has worked well for remote networkers, schooling, webinars and team workers stuck at home. At the end of March, the British Government used Zoom to host its first ever video-linked cabinet meeting, but debates rage on about Zoom's security and lack of end-to-end encryption. Like Houseparty, steps are needed to prevent 'zoombombing' or gatecrashing by outsiders. Zoom's 'Basic' package is free and offers a maximum 40-minute session with up to 100 participants: perfect for scheduling online school lessons, for example. For larger meetings, paid-for tariffs are available and it also works in Outlook, Chrome and Firefox, among others. If you're happy with its security, you can sign up at **Zoom.us** but be sure to read those all-important usage tips in the Resources area. British video-conferencing supplier Starleaf (**www.starleaf.com**), which owns its entire infrastructure, reports a boom in business for its certified high-security remote networking services due to the lockdown.

Video conferencing site Zoom offers 40-minute-long free sessions – check its security meets your needs.

Home is where you hang your @

With more of us staying at home or networking away from our workplaces, online security is obviously as important as ever. As someone who depends entirely on Internet access and a home network for a livelihood, I was recently asked about the risks that homeworkers might face during these challenging times. Top of my own list of precautions was ransomware prevention, followed by (obviously) virus protection. Aggressive ransomware can completely wreck a system by encrypting its files, as well as reaching across a home network and trashing network drives, meaning a lot of data can go up in smoke. (A reminder to never pay a ransom: it merely encourages crooks and there is no guarantee your files would be unlocked again anyway.) I described in previous columns how I take a local backup of last resort onto a removable USB pocket drive, or users might consider the cost (and speed) of cloud storage instead. Some archiving software such as Macrium Reflect stores backups in a proprietary format so, if disaster struck, both the original program and its software licence number would be needed before backups could be accessed again. If you decide to upgrade your PC, there is no guarantee that costly software can be ported onto a new machine: check licences for details.

At present, it pays to be vigilant by guarding against bogus 'CV19' emails, SMS text messages (smishing) and phony websites offering support, bogus health-care products or non-existent protection equipment, or mails that may click through to virus-infected websites that will steal personal data or load ransomware onto your system. Now is also a good time to think about removing your personal data from redundant online accounts. This can only help safeguard against personal data theft, especially from websites that play fast and loose with your private details hosted on their servers. Try **www.AccountKiller.com** for instructions on closing your account on a myriad of websites.

2FA is the way

Account hacking is as rife as ever, with crooks eager to hijack personal accounts for their own fraudulent purposes. To prove that even seasoned web users can fall victim to fraud, the author's own eBay account was hijacked by a gang of car criminals some years ago, who used it to try selling stolen motor vehicles online. The local police knocked on my door one morning and quizzed me, 'friendly fashion', about my newfound interest in online car sales. The crooks had somehow acquired my eBay logins from the dark web and changed the email address, before listing stolen trucks under my username, complete with a 100% seller rating.

To help combat fraud, users should set up Two-Factor Authentication (2FA) on their eBay, PayPal, Google, Microsoft and Amazon accounts, which requires the use of a one-time code to verify the user (see March 2020 *Net Work*). Microsoft and Google users can also install authenticator apps to help with this. Routine credit and debit card transactions are being toughened up due to EU legislation enforcing Strong Customer Authentication (SCA), with 2FA (eg, an SMS text with a one-time eight-character PIN) being utilised to authenticate some transactions. Although it should be pointed out that not even SMS messaging is totally secure, the benefits far outweigh the risks. It's becoming increasingly important to register a mobile phone number with banks, credit-card providers, PayPal and more, so check that your contacts details are up to date for your key online accounts. A useful tip: the Pushbullet app (Android only) can pop these 2FA text messages onto your PC desktop or tablet, so you can read them on-screen while you're still surfing online. Free lite versions of Pushbullet are available.

For those who are housebound or rarely use a mobile phone, BT landlines can automatically receive SMS messages using the BT text-to-voice service, though messages can be a bit difficult to understand at times. The author successfully configured PayPal 2FA texting to a mobile phone, with a BT 'Call Guardian' landline number as a backup.

FIDO, fetch!

Website logins have become the bane of every web user's life. The FIDO (Fast Identity Online) Alliance is a consortium dedicated to developing passwordless authentication instead, and a range of popular websites now interfaces with this form of added security. It doesn't cost much to get started and if you like the idea of using your own 'mechanical' key (or 'hardware token') instead of punching in passwords, then a Yubico Security USB key could be an answer. This popular Swedish USB device is designed to help prevent account takeovers or hijacking, and it utilises the U2F (Universal 2nd Factor) open standard devised by Yubico and Google, of which FIDO2 is the latest iteration.

The Yubico Security USB Key is an entry-level hardware token compatible with FIDO2 protocols for securing your logins. An NFC version is also available.

The entry-level Yubico USB key claims to work with Facebook, Twitter, various Microsoft online services, YouTube, United Kingdom GOV.UK logins, Gmail and many others with a simple touch on the key (check the data sheet at **https://tinyurl.com/rx9v8c7**). It's waterproof, battery-free and crush-resistant and is available from Amazon for just £19, or choose the NFC-capable model for £25 to tap on many mobile phones. It's a simple and portable way of implementing passwordless security, but do note that it will presently not work with certain websites such as eBay and Paypal that only use basic 2FA security. A directory of websites that support 2FA is at **https://twofactorauth.org** – a 'hardware token' tick implies that a website is compatible with a secure key, but check the website for confirmation if necessary. For higher security access, such as protecting a Windows, Linux or Mac logon, consider the Yubikey 5 Series instead, but the price leaps to

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0:52 / 3:22

Stepping out: the Floppotron by Polish engineer Paweł Zadrożniak plays melodies using some extreme stepper-motor action.

£45. Alternative 2FA hardware tokens are produced by Feitian, but check for FIDO2 compatibility.

A maxxed-out Humax

Last month, I recounted the tale of my Humax HDR-Fox T2 Freeview recorder that had nearly expired, risking the loss of stored programmes. I'm grateful to reader Ken Wood who emailed at length to suggest some workarounds. Ken is a regular long-service *Net Work* reader, having previously been in touch nearly a decade ago when I introduced the excellent new Humax HDR Fox-T2 in the first place. Last month, I lamented the dearth of comparable receivers and recorders on sale today and highlighted another reader's suggestion for a network-attached HD HomeRun Freeview receiver. Ken agrees, and added: 'Other than keeping our HDR-FOXes going, I believe the best way forward is open-source hardware and software. We don't have sufficient incentive as yet, but as more of our FOXes fail (I have three running, one cold spare, and two more out on loan) I anticipate users might collaborate on putting together a Linux system from standard parts (eg Raspberry Pi-based) with DVB-T2 USB dongles, and some kind of open-source home theatre OS.' Until then, my defunct Humax recorder awaits a tear-down and I also noted that, inexplicably, my Samsung Smart TV has now taken to changing HDMI source at 8.55 pm every night all by itself.

Time for some fun

It's always a pleasure to watch engineers on YouTube showing their skills, and the Italian constructor Daniele Tartaglia demonstrates his lateral thinking using a handful of parts and an awful lot of imagination. If you have 30 minutes to spare, take a peek at Daniele's talent, starting with seven things to do with a fan, at **https://youtu.be/sb-pyno-qPmU**. His Mini CNC plotter is made from old DVD drives, see **https://youtu.be/Q5ma1HDuotk**. Daniele's YouTube channel is worth looking at, and he's also on Facebook.

We all know the whining and buzzing noises that stepper motors make, but take a stack of 64 floppy disk drives, add a pair of screeching flatbed scanners, an array of bare hard disks mixed in with an Arduino or two, and the result is the Floppotron, an amazing electronic musical instrument created by Polish engineer Paweł Zadrożniak. But I won't spoil the fun – head over to YouTube and enjoy **https://youtu.be/C9qy0utP2QM** for starters.

Some elegant examples of simple circuits tacked together with point-to-point wiring can be found on YouTube's 'SR electric' channel, including **https://youtu.be/QCbe8eMbcW4**. It will be ideal for inspiring younger constructors, and no printed circuit board is required!

Last, this month, an overdue update about *PE's* online presence: our all-new website is at an advanced stage of development, with a lot of work going on behind the scenes. Among other things, it will soon be possible to buy pre-programmed PIC chips for projects via the new shopping cart, where free downloads of monthly files can also be accessed. We have been juggling with two websites and are sorry that the planned update has taken us longer than expected, but it will be ready soon and I'll be bringing more news about *PE's* website in next month's *Net Work*. In the meantime, we're always happy to handle readers' email queries sent to the usual address: **pe@electronpublishing.com**

The author can be reached at:
alan@epemag.net

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AM/FM/CW Scanning HF/VHF RF Signal Generator

Part 1
by Andrew Woodfield ZL2PD

This low-cost, easy-to-build and user-friendly RF signal generator covers from 100kHz–50MHz and 70–120MHz, and is usable up to 150MHz. It generates CW (unmodulated), AM and FM signals suitable for a wide range of tests. Its output level is adjustable between -93dBm and +7dBm and it has an accurate frequency display. It also includes a scanning function for filter alignment.

I've always wanted a good AM/FM HF/VHF signal generator. I have tried to meet that need with a variety of designs over the years, some analogue, others using DDS chips.

Recently, I have tried low-cost fractional-N oscillator chips, including the Si5351A. These were only suitable in specific circumstances, and did not make for a good general-purpose test instrument.

Obviously, it's possible to purchase an RF signal generator, new or used, but I couldn't afford the price of a good one. Cheap signal generators lack adequate performance and useful functions. Those with adequate performance are usually too expensive for most hobbyists, or are unreliable and difficult and/or expensive to maintain.

I have seen some designs published, but these are typically simple analogue LC-based designs with coverage up to around 150MHz, in a series of five or six switch-selected bands.

Most lack accurate frequency readouts or adequate stability. Spurious and harmonic outputs can also be a problem.

(See the list of references at the end of this article for three such designs that I considered and rejected).

Table 1 (overleaf) shows what is available at the moment. I rejected all of these options for one reason or another – inadequate performance, lack of features, high price or unreliability.

With few exceptions, the output levels of most of these generators are quite limited. Those with a variable output level typically use a simple potentiometer, with little regard to varying output impedance or accuracy.

Output levels are also often too low for use in many typical applications.

Modulation, where available, is often limited. And, finally, some otherwise useful digital-based designs are now difficult or impossible to build due to obsolete parts or unavailable software or PCB layouts.

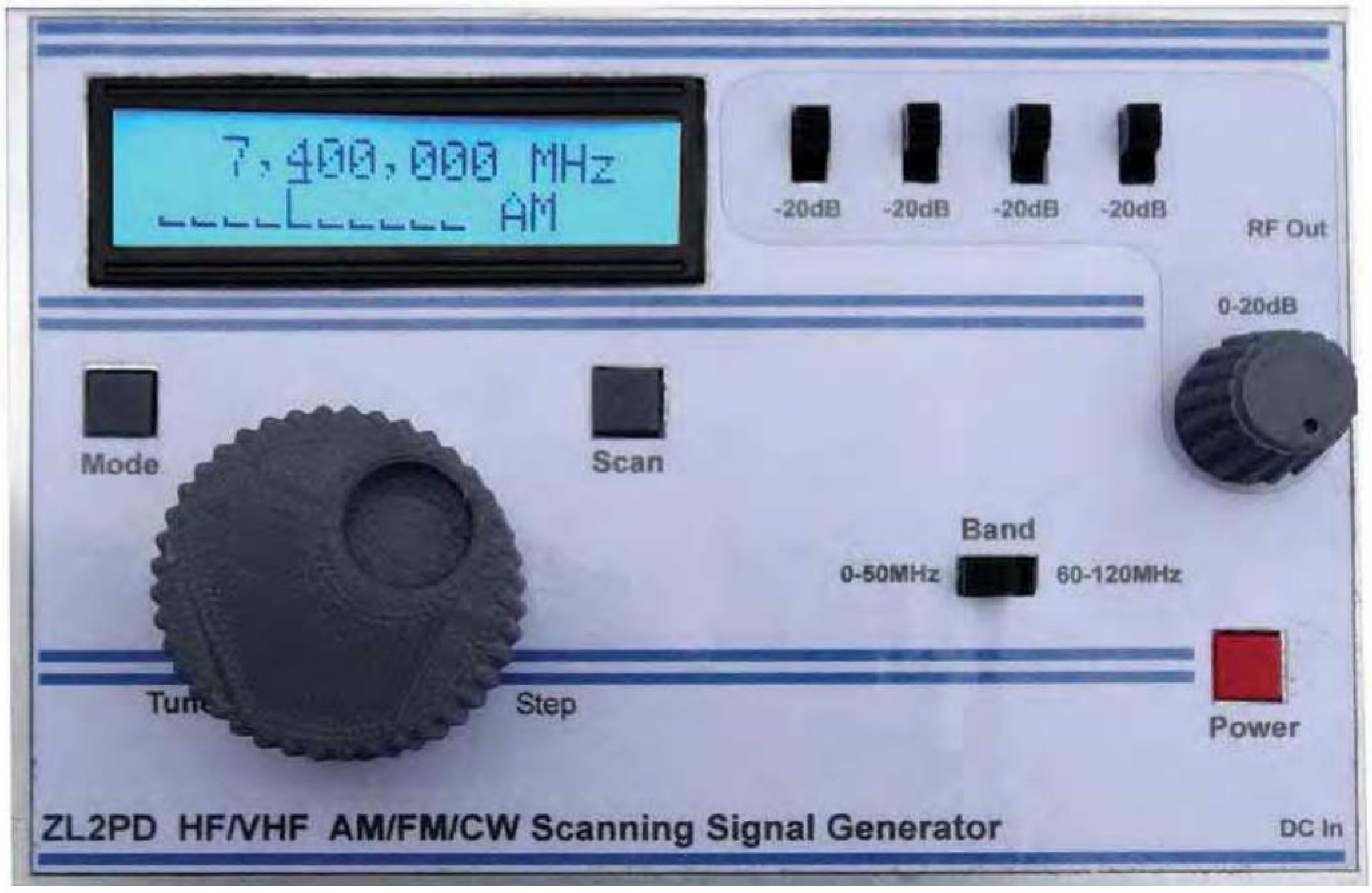
Basic analogue and digital PLL-based RF signal generators are available between about £100 and £150. The analogue generators offer basic CW, AM or FM modulation. Output level and modulation depth on the low-cost analogue generators are typically controlled via internally mounted trimpots adjusted through small holes in the panel.

The low-cost digital signal generators only offer FM and appear aimed at the two-way radio industry.

These instruments are perfectly functional, but for hobbyists, the features are too limited. To use them effectively, you'd need extra equipment such as a frequency counter, attenuators, amplifiers and a level meter. It's far easier to have these features built into the generator.

As Table 1 shows, moving up in the market significantly increases the price. Used equipment is available at lower cost, but many otherwise excellent instruments have recognised spare parts or reliability issues as the equipment ages.

So I needed to come up with my own design that would tick all the boxes, and that is just what I have done. See the table opposite which lists its features and performance figures.



Design goals

This design represents the outcome of an extended period of development and testing over the last few years.

This signal generator provides basic CW (unmodulated) signals, plus AM and FM modulation functions, primarily across the high frequency range from 100kHz to 30MHz, with a continuously variable output level suitable for most requirements.

This frequency range includes most common IFs (intermediate frequencies) such as 455kHz, 465kHz, 470kHz, 10.7MHz and 21.4MHz.

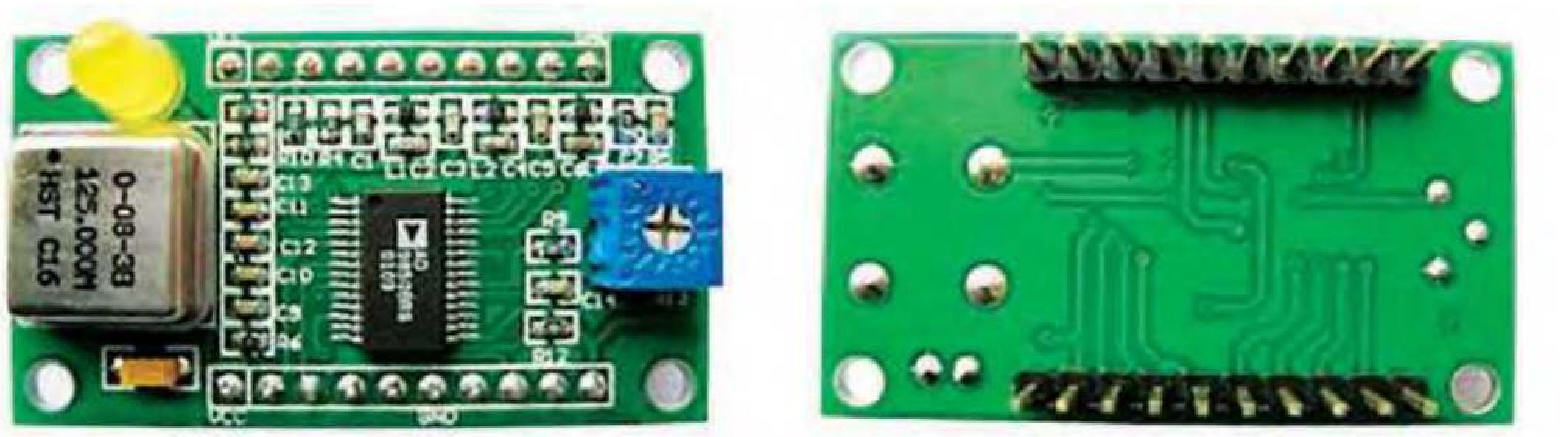
Coverage extends to 50MHz, with another range covering 70-120MHz. Coverage actually extends up to 150MHz with some limitations, to permit limited use in the popular 2m amateur radio band, as well as parts of the widely used international 138-174MHz land mobile band.

Key design objectives included low cost, ease of obtaining parts and ease of construction. Special parts, such as chip-based attenuators, for example, were avoided in favour of the low-cost combination of slide switches and standard resistors.

The generator's RF output is designed for applications requiring relatively high RF levels. These include testing double-balanced diode mixers in high-performance receivers and for testing multi-stage passive filters, where stop-band attenuation measurements require relatively high signal generator outputs.

Lower RF output levels are also useful, eg, for receiver sensitivity tests. The minimal useful level is mostly determined by the limitations of low-cost shielding and the simple hobbyist construction methods used.

If an enclosure was carefully milled from a 25mm thick metal billet with shielding slots for flexible conductive inserts, the lower limit could be extended significantly, but relatively few hobbyists could achieve this. So I've used simple shielding and a basic DIY folded aluminium sheet metal box. This is reflected in the modest lower output specification limit of around –90dBm.



This is the low-cost AD9850-based DDS signal generator used in this design. Besides the chip, it has a reference osciallator (the metal can at left) plus a number of discrete components, including a low-pass filter for the output.

Achieving that performance, however, still requires moderately careful enclosure construction.

By using commonly available parts and low-cost modules, I have been able to keep the overall cost low. I estimate the cost to build this signal generator currently at around £40.

Design approach

As shown in Fig.1, a modern signal generator consists of five functional blocks: the RF oscillator, modulator, RF buffer amplifier, variable attenuator to control the output level, and some control electronics. The logical implementation of the control electronics is based on a microcontroller. The final block is the power supply, either battery-powered or mains-powered (or both).

The oscillator is a key element of any signal generator. An analogue-based wide-range oscillator and modulator involving sets of inductors and a tuning capacitor is impractical and can't provide the desired functions and performance required at a modest cost.

The cheapest digital options include the powerful Silicon Labs Si5351A device or widely available direct digital synthesis (DDS) modules based on chips such as the Analog Devices AD985x (see our article on the AD9850 in the September 2018 issue of *PE*.

Other digital options include PLL chips such as the Maxim MAX2870. While it is certainly possible to generate sinewaves from both the Si5351A and the MAX2870, the additional circuitry required to obtain low harmonic content output signals, coupled with the challenges of adding modulation, make them less attractive.

AD9850 DDS modules (shown above) are available from ebay and AliExpress at reasonable prices.

The instrument's display requirements are modest, so I decided to use a common 16×2 character alphanumeric LCD. These are easy to read and drive from a micro.

Features and specifications

	Specification	**Comments**
Coverage	100kHz-50MHz, 70MHz-120MHz	Usable up to 150MHz
Tuning steps	10Hz to 1MHz in decade increments	User selected
Accuracy and stability	Within 150Hz at 30MHz (typical), 0-40°C, 0-80% humidity	Can be enhanced with software calibration
Output level	–93dBm to +7dBm (approximate)	50Ω termination
Attenuation steps	0-80dB in 20dB steps (switched) + 0-20dB (variable)	
Output socket	SMA	
Spurious and harmonics	Typically better than –30dBc	Within specified coverage frequency range
AM	30% modulation @ 1kHz	
FM	NB (12.5kHz spacing), 1.75kHz deviation @ 1kHz (60%)	
	WB (25kHz spacing), 3kHz deviation @ 1kHz (60%)	
	BC (12.5kHz spacing), 50kHz deviation @ 1kHz (60%)	Suitable for standard broadcast FM receivers
Scanning	Programmable start and stop frequencies	1kHz resolution
	10, 20, 50, 100, 200 or 500 steps/sweep	Auto step-size calculation
Display	16x2 alphanumeric LCD	
Power control	Soft on/off switch	
Controls	Two knobs and eight switches	
Power supply	9-12VDC at 250mA	
Dimensions	160 x 110 x 25mm (excluding knobs)	
	160 x 110 x 45mm (including knobs)	
Weight	~250g	

PRODUCT	TYPE	PRICE BAND ($US)	FREQUENCY COVERAGE	OUTPUT	MODULATION	FEATURES
Generic brands	Analog	\$150–\$200	100kHz–150MHz in six bands	0–100mVpp	Basic AM, FM	Analog dial, internal presets for user controls
Generic brands	Digital PLL?	\$150–\$200	500kHz–470MHz	–132 to –70dBm	CW, FM	2 line x 16 char LCD display
RF Explorer	PLL and dividers	\$200–\$300	24MHz–6GHz	–40 to 0dBm	None	Sweep functionality
ERAsynth	PLL, controlled by user PC or smart device	\$950	250kHz–6GHz	–60 to +15dBm	AM, FM, pulse via external apps	Software apps control functionality
Digimess SG200	Digital	\$2500	9kHz–450MHz	–127 to +13dBm	AM, FM, FSK, PSK	Sweep functionality
Used signal generators, eg Marconi 2022, HP8640	Digital/PLL	\$500–\$1000	10kHz–1000MHz	–127 to +13dBm	AM, FM, FSK, PSK	Excellent performance, but some models have recognised maintenance issues
Keysight, R&S, Tektronix, IFR, TTi, Rigol, Gratten, etc.	Digital	\$3000–\$20,000+	10kHz–15GHz (depends on model)	–140 to +20dBm, typically	All (AM, FM, PM, FSK, QPSK, etc.)	Extensive array of features and functionality

Table 1: I looked at a range of currently available commercial equipment, both new and used. However, for anything that had better-than-mediocre performance, that third column definitely caused me some heartache! I estimate the instrument described here could be built for not much more than £40, plus case.

A rough outline of the design began to take shape and, adding up processor pins required, the very common ATmega328P 8-bit microcontroller appeared suitable. While an Arduino was briefly considered, I would need to use practically every pin on the device, and I wanted to keep the instrument compact, so I decided to use a standalone ATmega328 processor.

The RF buffer amplifier requires only modest gain. It must handle the somewhat unusual 200Ω output impedance of the AD9850 module and the following 50Ω attenuator stages and 50Ω output. Another consideration is that the buffer should not be overloaded by the sometimes high output swing of the AD9850. Numerous designs published on the Internet suffer from this problem.

The buffer should also maintain its gain across the design frequency range. And the buffer should be able to work into a reasonable range of loads and survive typical bench treatment.

I've used MMIC amplifiers such as the ERA-series devices from Mini-Circuits to buffer AD9850, AD9851 and AD9854 DDS chips in the past. These drive 50Ω loads with good performance.

However, in testing this signal generator with a wide variety of filters, amplifiers, receivers, transmitters and other loads, several MMICs suffered early deaths. These were probably due to the very low impedances presented by some of the test filters.

The search for a more suitable buffer stage was ultimately concluded with the inclusion of a traditional single-stage buffer amplifier using a robust 2N4427 VHF transistor. It is widely available at low cost, as is its near-equivalent, the 2N3866. It proved more than adequately robust over many months of use. The TO-39 case of the transistor becomes warm during use, but a heatsink is not required.

The design of the attenuator stage also posed some challenges. Recently, PE4302 30dB step attenuator chips have become popular. While only relatively new devices, these have recently been listed by the manufacturer as obsolete. The replacement devices, while having improved performance, also come at a substantially increased price.

Relay-controlled fixed attenuators can be used, but with an eye on cost and simplicity, I decided to use inexpensive slide switches instead. Experience has shown these to perform adequately for this type of application. However, these limit the attenuator steps to specific attenuation values. Ideally, the generator should have a fully variable output level.

So I decided to build and test a Serebriakova attenuator as an alternative to a more costly PIN diode-based design. This configuration is shown in the lower right-hand corner of Fig.4, the circuit diagram.

It's a simple passive resistor network that acts as a variable attenuator, well suited for basic designs like this. Apparently of Russian origin, the attenuator network uses a 500Ω linear potentiometer to give a 20dB variable attenuation range. It works well into mid-VHF frequencies.

The input impedance is maintained reasonably close to the desired 50Ω across the adjustment range of the potentiometer, so the attenuation is predictable. The output match to 50Ω as the potentiometer is adjusted is not perfect, but it's an acceptable compromise for this design.

Amplitude modulation with the AD9850

A key objective of the signal generator was to deliver both amplitude (AM) and frequency modulation (FM), as well as providing an unmodulated RF signal.

Amplitude modulation with the AD9850 is well documented. Analog Devices, the chip's manufacturer, helpfully published an application note (AN-423) which describes adding a small-signal NMOS FET and a few additional parts to do this. A quick test confirmed that it works as described.

Most signal generators use a 1kHz modulation tone, which can be produced in several ways. One approach is to use the ATmega328 to generate a 1kHz square wave using one of its internal timers and then filter this to give a 1kHz sinewave. But extensive filtering is required to obtain a suitable tone. That involves quite a few extra parts.

A second, similar approach is to use the ATmega328's counter/timer in its pulse-width modulated (PWM) mode. The resulting waveform is closer to a sinewave but still requires some filtering to remove the 31kHz PWM frequency. Usefully, that filter is far less complex given the much higher clock frequency compared to the 1kHz tone.

A third option is to build a discrete 1kHz sinewave oscillator and just use the ATmega328 to turn it on and off as required. At first glance, the discrete oscillator approach is attractively simple and uses relatively few components, so I tested this out, using the circuit shown in Fig.2.

It works quite well. The 3.3nF capacitor value can be adjusted to give the required modulation level at the AD9850's RF output. This works by

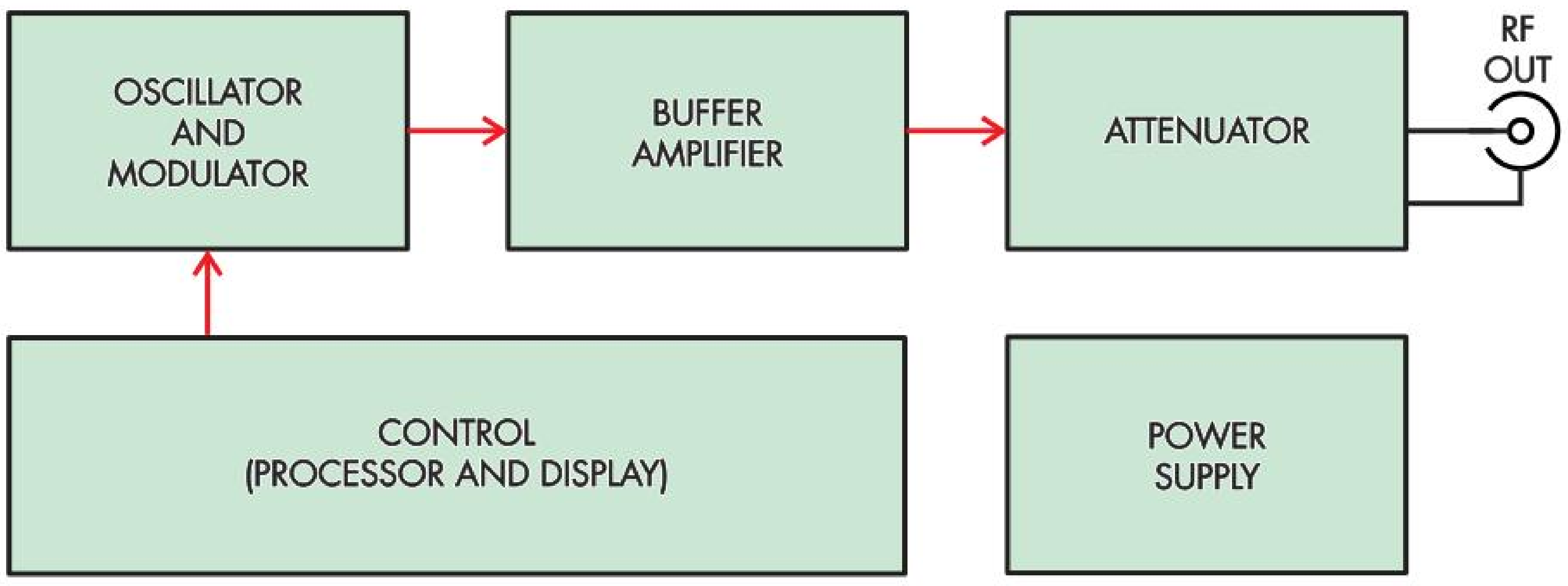


Fig.1: the basic arrangement of a modulated signal generator with adjustable output level. Our design follows this configuration.

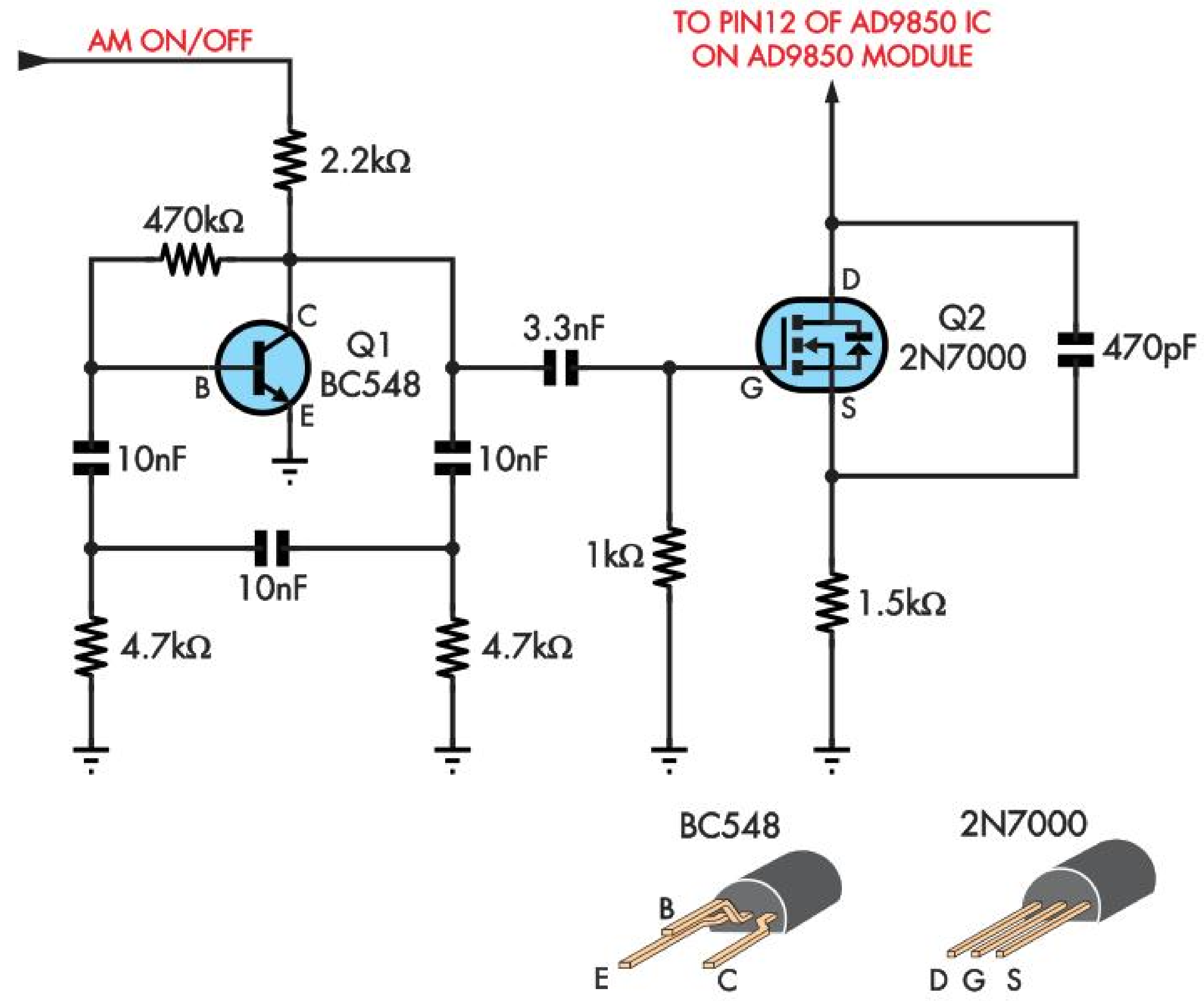


Fig.2: a typical example of how you can apply amplitude modulation to the output of an AD9850-based signal generator module using discrete components.

In the end it was decided to abandon this idea in favour of a PWM-based microcontroller approach.

replacing the fixed resistor (RSET) on pin 12 of the AD9850, typically 3.9kΩ, with the variable resistance of Q2's channel. This resistance sets the AD9850 digital-to-analogue converter (DAC) current and, subsequently, the AD9850 RF output level.

By varying the gate voltage of the 2N7000 at 1kHz using the voltage from the collector of audio oscillator Q1, the AD9850 RF output is amplitude modulated. However, this analogue tone is not precisely 1kHz. Its frequency is determined by the passive components around Q1. To give a more accurate (and potentially adjustable) modulation frequency, the PWM-based approach was used in the final circuit. See the 'OUTPUT LEVEL CONTROL' section in Fig.4.

Pin 11 (output PD5) of IC1 produces the 1kHz sinewave as a 31kHz PWM square wave, or potentially at other frequencies by changing the software. This is filtered and used to control a current sink made using standard NPN transistors. An extra 100nF bypass capacitor was added to pin 12 to the final PCB to address AD9850 module stability.

The 31kHz pulse-width modulated 1kHz signal is produced by the ATmega328 from its 8MHz internal RC oscillator. The variable DC voltage of 0-5V arriving on the base of Q1 is converted to a variable collector current in Q1 of 0-700µA, the maximum current value being set by its 1kΩ emitter resistor. This figure was selected to exceed the 625µA maximum current sink range required by the AD9850.

This approach is not perfect. Using the RSET pin and the standard unbalanced RF output from the AD9850 module, the typical approach used in these low-cost modules, the output modulation produced is asymmetric. In practice, however, this does not matter terribly.

This simple circuit delivers clean-sounding amplitude modulation with the AD9850 and uses fewer components than the other options. It also allows other modulation tones to be added in future if required. Finally, this approach also adds another important feature – reasonably accurate linear control of the AD9850 RF output level.

Note though that this approach requires the removal of that 3.9kΩ resistor from the module as supplied, and the addition of a wire to control pin 12 from Q1 to one of its pads. This change will be described in more detail later.

Frequency modulation (FM)

Again, there are several options to produce FM with the AD9850. One approach would be to externally modulate the AD9850's separate 125MHz reference crystal oscillator. Frequency and phase modulation could be both implemented this way. Unfortunately, the 125MHz reference oscillator in the low-cost modules is inside a sealed metal can.

There is no external voltage tuning input which might otherwise be pressed into use to produce FM. It's possible to replace the reference oscillator module with a discrete oscillator to allow for external modulation, but that takes some effort. It is also possible to use the AD9850 internal phase modulation register but resolution is too limited (4 bits).

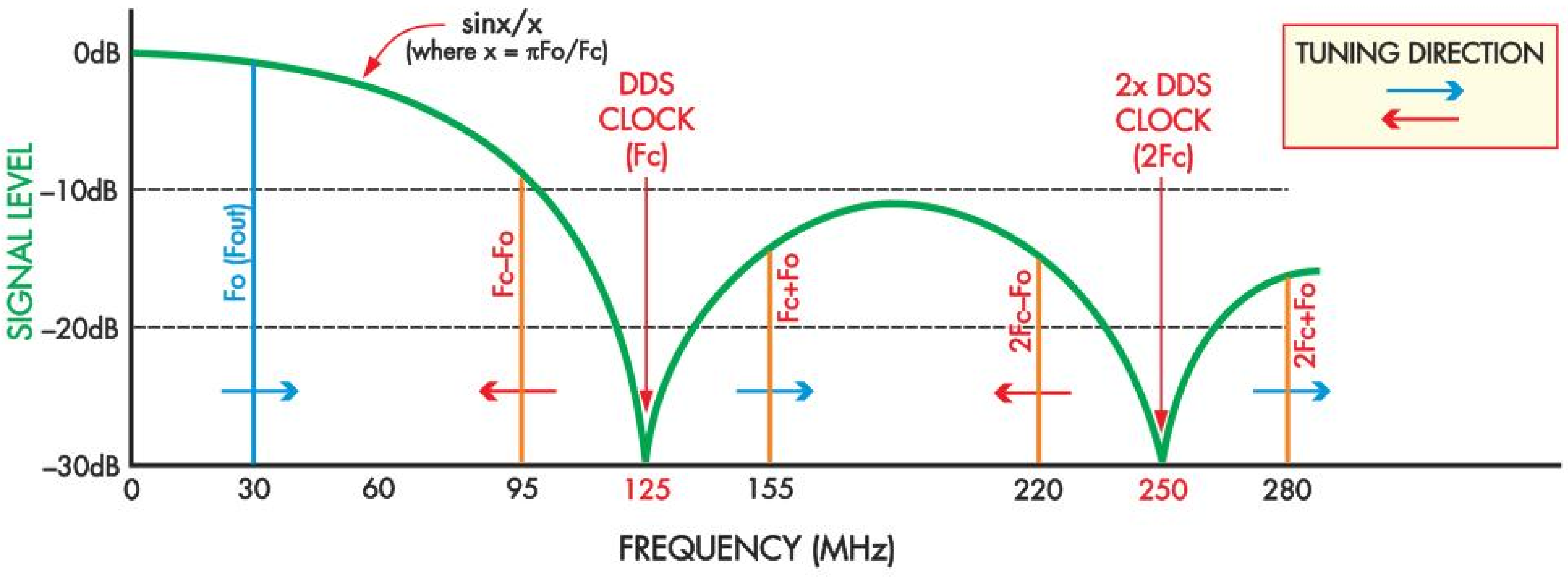


Fig.3: the output of a DDS signal generator module contains the wanted frequency plus a number of alias frequencies. These are normally filtered out but it is possible to instead filter out the fundamental frequencies and keep one of the higher alias frequencies to extend the signal generator's range.

What is Frequency Modulation (FM)?

With frequency modulation, the audible tone of (say) 1kHz results from the carrier frequency of the signal generator being instantaneously shifted (or 'deviated') from its nominal frequency in proportion to the amplitude of the modulating tone.

As the amplitude of the tone increases, at that 1kHz rate, the carrier frequency of the generator proportionally increases. Similarly, as the 1kHz tone's amplitude decreases, the carrier frequency is proportionally decreased. It is proportional because the extent of the carrier frequency shift, or deviation, depends on the signal bandwidth required.

For broadcast radio FM, the peak deviation is ±75kHz. The resulting signal fills the standard FM broadcast channel bandwidth of 200kHz. Traditional VHF FM two-way radio transceivers used for amateur radio or commercial/government mobile radio use a much smaller ±5kHz deviation, and these signals occupy 25kHz channels.

More modern so-called 'narrow-band' amateur FM transceivers typically use ±2.5kHz deviation, and these use more densely-packed channels spaced apart by 12.5kHz.

Another Analog Devices application note (AN-543) suggests a solution. It describes a powerful Analog Devices DSP chip which samples incoming stereo audio at 48ksamples/sec and then sends a stream of 40-bit frequency-setting words serially at very high speed to the AD9850.

Each of these 40-bit words programs the AD9850 to a new instantaneous frequency, which is necessary to emulate a stereo FM signal (including the 19kHz and 38kHz pilot tones).

With some care and a few lines of assembly code for speed where necessary, the ATmega328 can modulate the AD9850's output frequency in this manner. Sadly, the resulting modulation sounds pretty average. The problem is the time required by the ATmega328 to send the serial string of 40 bits to the AD9850 each time its frequency has to be updated for frequency modulation via the typical 3-wire interface.

The poor result is not surprising. With the conventional serial load method and our 8MHz, 8-bit chip, it is (just!) possible to load four modulation samples per 1kHz cycle into the AD9850. A four-point sinewave is actually a triangle wave, which is full of harmonics!

Closer study showed that there is another way to communicate with the AD9850 chip. Almost every AD9850/51 based design uses the three-wire serial bus to send 40-bit control words to the AD9850 each time the frequency needs to be updated.

However, the AD9850 can also be controlled using a parallel interface. This requires sending five 8-bit words in quick succession to the chip, along with some control signals via two or three additional pins. The only published example I could find is based on a PIC processor.

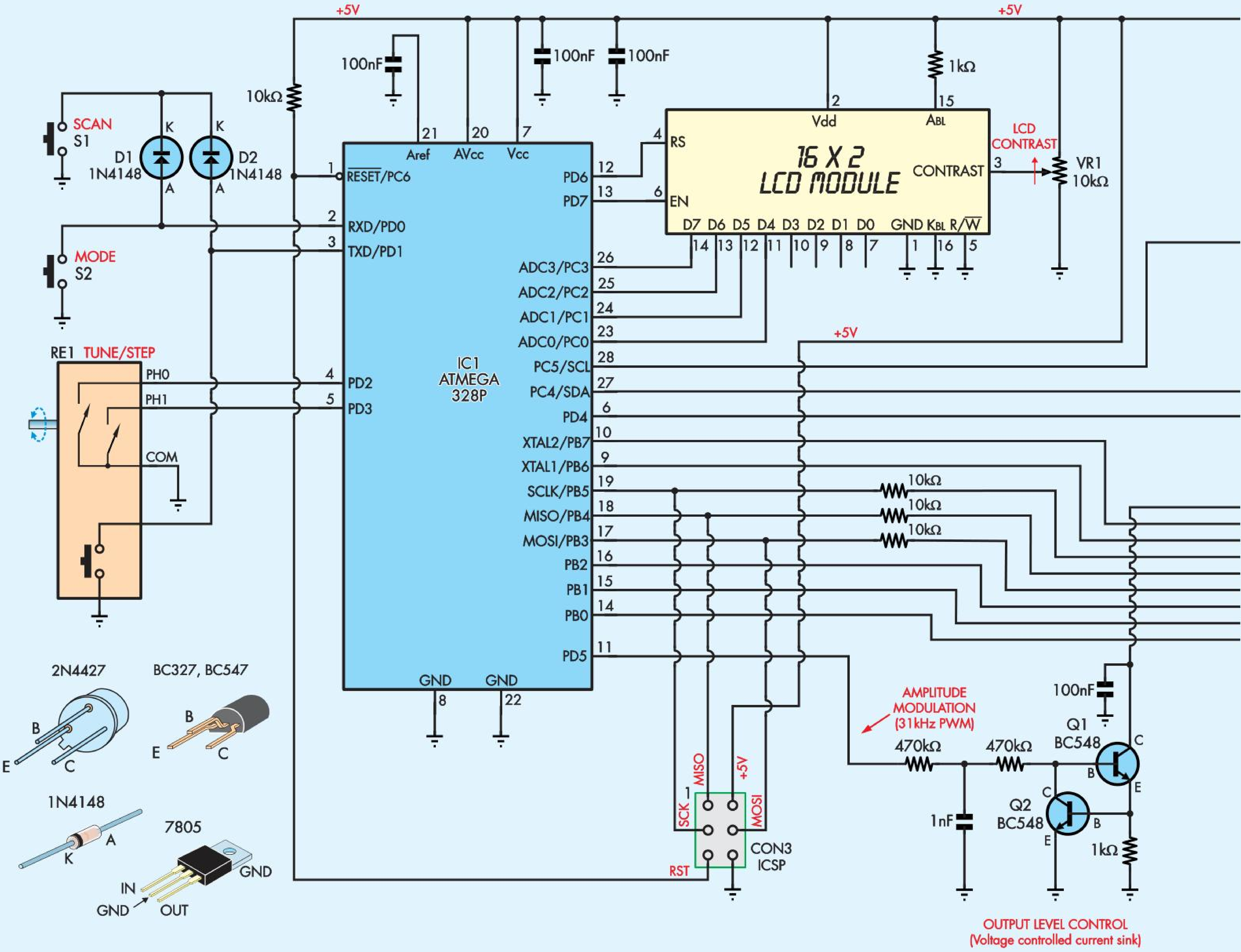
There is a considerable advantage in this method. Rather than taking about 250µs for the ATmega328 to load each 40-bit word serially, the parallel approach can reduce this to as little as 2.5µs.

With the parallel loading method, it is possible to send 20 samples per 1kHz cycle without any trouble at all, even with the (relatively) slow 8MHz clock in the ATmega328. This is much closer to a proper sinewave. The difference is clearly audible in an FM receiver. The parallel method gives a demodulated signal that sounds very clear and clean, just like a sinewave should.

So for FM, the 20-point sampled waveform is created by calculating the required AD9850 output frequency every 50µs and sending that data over the fast parallel interface.

The FM deviation is controlled by changing the magnitude of the frequency changes which occur 20,000 times per second (20 points × 1kHz).

Selecting narrow band FM (the LCD shows 'FM-NB') on this generator for 12.5kHz spacing for FM two-way


+5V
100nF
100nF
100nF
10kΩ
1kΩ
SCAN
S1
D1
1N4148
D2
1N4148
K
A
MODE
S2
RE1 TUNE/STEP
PH0
PH1
COM
Aref
AVcc
Vcc
RESET/PC6
RXD/PD0
TXD/PD1
PD2
PD3
IC1
ATMEGA
328P
PD6
PD7
ADC3/PC3
ADC2/PC2
ADC1/PC1
ADC0/PC0
PC5/SCL
PC4/SDA
PD4
XTAL2/PB7
XTAL1/PB6
SCLK/PB5
MISO/PB4
MOSI/PB3
PB2
PB1
PB0
PD5
GND
GND
Vdd
ABL
RS
EN
16 X 2
LCD MODULE
CONTRAST
D7 D6 D5 D4 D3 D2 D1 D0
GND KBL R/W
LCD CONTRAST
VR1
10kΩ
10kΩ
10kΩ
10kΩ
AMPLITUDE MODULATION (31kHz PWM)
470kΩ
470kΩ
1nF
Q1
BC548
Q2
BC548
1kΩ
100nF
SCK
MISO
+5V
MOSI
RST
CON3
ICSP
OUTPUT LEVEL CONTROL
(Voltage controlled current sink)
2N4427
BC327, BC547
B
E
C
1N4148
A
K
7805
IN
GND
OUT
GND

AD9850-based CW/AM/FM HF/VHF Signal Generator

Fig.4: along with the 16×2 LCD module, the ATmega328P microcontroller (IC1) drives the AD9850 signal generator module using an 8-bit parallel bus plus three control lines. This allows it to modulate the output frequency at 20kHz, which results in clean 1kHz frequency modulation. Amplitude modulation is applied using PWM from pin 11 of IC1, which is filtered and then controls a current sink comprising transistors Q1 and Q2. The resulting current flow controls the signal generator output level. The output signal is buffered by transistor Q3 and then passes four switched 20dB attenuators and then a 0-20dB variable attenuator (VR2) which gives a 100dB overall output range. Q4 and Q5 form a 'soft power' switch for the circuit, which is controlled by pushbutton switch S3.

radios produces ±1.5kHz FM; selecting wideband FM, for older 25kHz-channel-spaced two-way radios, gives ±3kHz FM ('FM-WB'), while selecting broadcast FM produces ±50kHz FM signals ('FM-BC').

Frequency scanning

A further feature was added for testing and aligning filters. For example, while designing this *Signal Generator*, I was also building a 9-band HF transceiver. Its receiver front end features nine sets of coupled tuned circuits, each requiring careful alignment, with three or four adjustments per set.

In the scanning mode, the generator briefly produces a signal on a series of discrete frequency steps across a defined range. For the transceiver example, the *Signal Generator* could be programmed to produce signals across each of the nine bands used for the bandpass filters being tested.

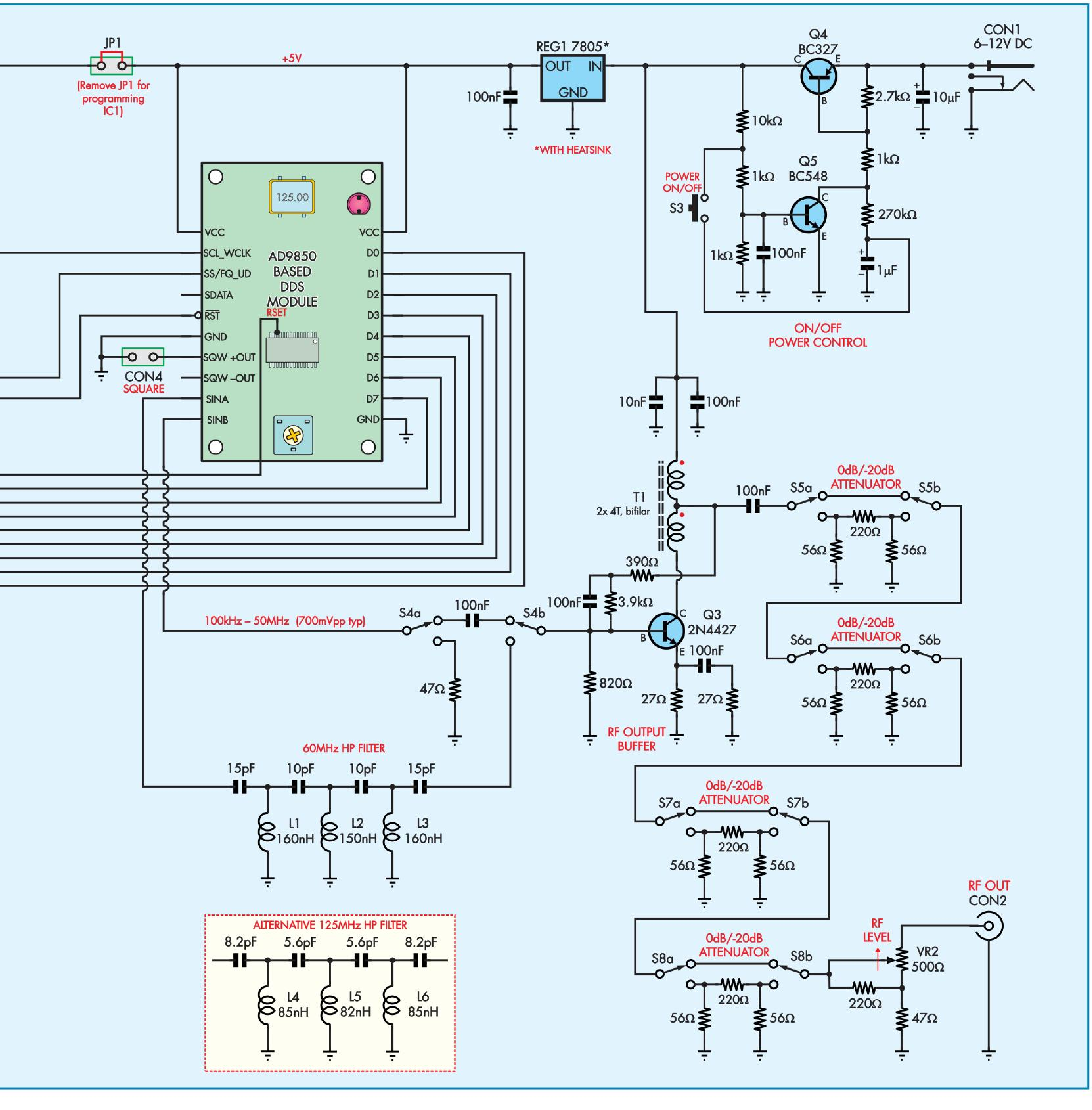
By monitoring the amplitude of the resulting output from each filter on an oscilloscope, it is possible to quickly align each filter while seeing the impact of every change. This forms, in effect, a 'poor man's spectrum analyser'. This saves considerable time and effort over manual alignment methods.

The start and stop frequencies can be set anywhere across the range of the signal generator. Since filters are generally fairly broad, a 1kHz step size for setting the start and stop frequency is acceptable.

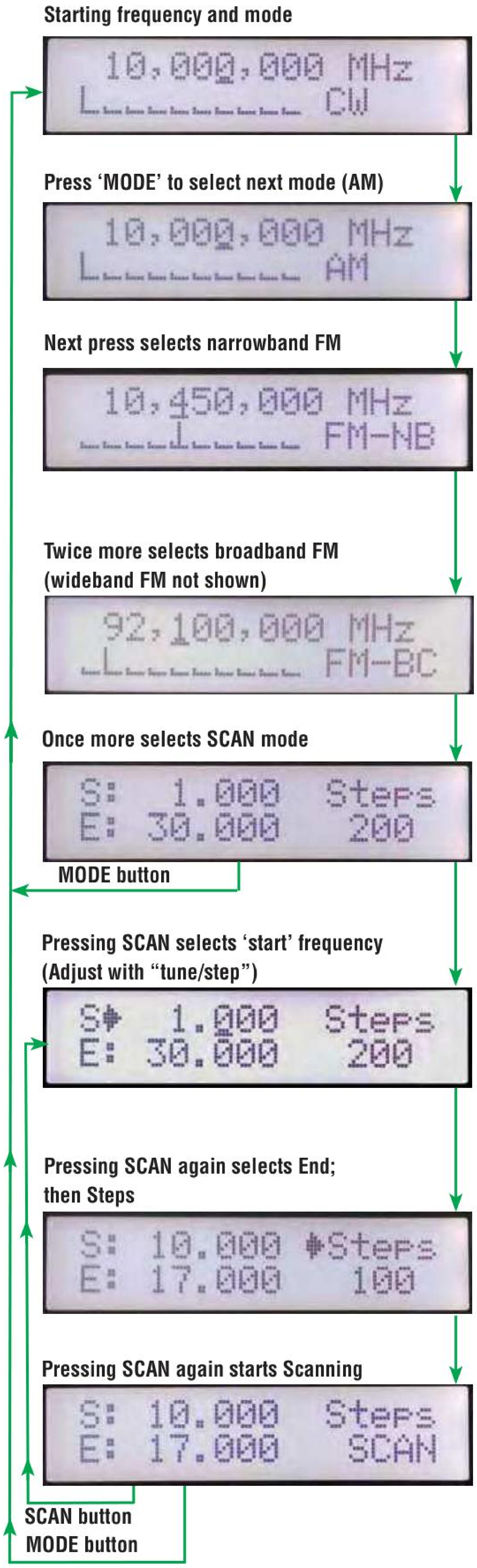
I decided to add a SCAN pushbutton to the design, to enable this mode. As I had run out of pins on the ATmega328, I used two diodes (D1 and D2) so that pressing this button is effectively equivalent to pressing the two existing buttons (MODE and STEP) simultaneously. The micro can detect this as a press of the SCAN button – see Fig.4.

Expanded frequency coverage

Typical AD9850 modules are fitted with a 125MHz reference oscillator. DDS oscillators deliver clean sine outputs up to about 30% of the reference frequency; in this case, say 40MHz.


JP1
(Remove JP1 for programming IC1)
+5V
REG1 7805*
OUT
IN
GND
100nF
*WITH HEATSINK
Q4
BC327
C
E
B
CON1
6–12V DC
2.7kΩ
10µF
10kΩ
1kΩ
Q5
BC548
POWER ON/OFF
S3
1kΩ
B
C
E
270kΩ
1kΩ
100nF
1µF
ON/OFF POWER CONTROL
125.00
VCC
SCL_WCLK
SS/FQ_UD
SDATA
RST
GND
SQW +OUT
SQW –OUT
SINA
SINB
AD9850 BASED DDS MODULE
RSET
VCC
D0
D1
D2
D3
D4
D5
D6
D7
GND
CON4
SQUARE
10nF
100nF
T1
2x 4T, bifilar
100nF
S5a
0dB/-20dB ATTENUATOR
S5b
220Ω
56Ω
56Ω
390Ω
100nF
3.9kΩ
Q3
2N4427
C
B
E
100nF
100kHz – 50MHz (700mVpp typ)
S4a
100nF
S4b
47Ω
820Ω
27Ω
27Ω
RF OUTPUT BUFFER
S6a
0dB/-20dB ATTENUATOR
S6b
220Ω
56Ω
56Ω
60MHz HP FILTER
15pF
10pF
10pF
15pF
L1 160nH
L2 150nH
L3 160nH
S7a
0dB/-20dB ATTENUATOR
S7b
220Ω
56Ω
56Ω
RF OUT
CON2
ALTERNATIVE 125MHz HP FILTER
8.2pF
5.6pF
5.6pF
8.2pF
L4 85nH
L5 82nH
L6 85nH
S8a
0dB/-20dB ATTENUATOR
S8b
220Ω
56Ω
56Ω
RF LEVEL
VR2
500Ω
220Ω
47Ω

NAVIGATING THE MENUS


Starting frequency and mode
10,000,000 MHz
CW
Press 'MODE' to select next mode (AM)
10,000,000 MHz
AM
Next press selects narrowband FM
10,450,000 MHz
FM-NB
Twice more selects broadband FM
(wideband FM not shown)
92,100,000 MHz
FM-BC
Once more selects SCAN mode
S: 1.000 Steps
E: 30.000 200
MODE button
Pressing SCAN selects 'start' frequency
(Adjust with "tune/step")
S: 1.000 Steps
E: 30.000 200
Pressing SCAN again selects End;
then Steps
S: 10.000 Steps
E: 17.000 100
Pressing SCAN again starts Scanning
S: 10.000 Steps
E: 17.000 SCAN
SCAN button
MODE button

Increasing but acceptable levels of aliasing products are present in the output spectrum up to 45% of the reference frequency, say 50MHz.

Beyond this, as the output frequency approaches the Fourier limit of about 60MHz, spurious products render the output unusable.

Cheap modules are usually supplied with an onboard elliptical low-pass filter with a cutoff frequency of 70MHz to maximise the output frequency range. In fact, these modules have three outputs. The first is the filtered output as described. It appears on my module on the pin labelled 'SINB'.

An adjacent pin, 'SINA', might appear to be similar. However, this signal comes directly from the AD9850 DAC. It is a 180° phase-shifted (inverted) version of the signal at SINB but without any additional low-pass filtering.

The third available output comes from an internal comparator in the AD9850. It produces a square wave version of the output. This is output level dependent, the duty cycle being set by adjusting a miniature trimpot on the module. If it is adjusted for a good 50% duty cycle output at a lower frequency setting, it tends to be less accurate at higher frequencies.

There is little difficulty in obtaining reasonably clean filtered signal generator outputs up to 50MHz from the filtered (SINB) pin. Some testing showed that output was acceptable down to 100kHz. That's useful for covering receiver intermediate frequencies (IF) and IF filters between 455kHz and 470kHz, for example.

Looking more closely at the module, the second SINA output looked potentially useful too. Because this output is not filtered, the full set of DDS alias frequencies are available here.

In one example, illustrated in Fig.3, the 'wanted' output (labelled Fout) is at 30MHz. As the user increases this frequency, tuning towards 35MHz for example, this output frequency increases, shown by the blue arrow.

At the same time, the AD9850 (like all DDS chips) also produces 'alias' frequencies. These are shown in orange. The nearest is at 95MHz, ie, the clock frequency of the DDS (125MHz) minus 30MHz. It decreases in frequency as the user tunes from 30 to 35MHz, ending up at 90MHz (ie, 125-35MHz).

There are many other alias frequencies which are produced simultaneously, the next nearest being at 155MHz (the clock frequency of 125MHz plus 30MHz), with others at 220MHz, 280MHz and so on, theoretically continuing forever. The direction these alias outputs tune can be seen by the direction of the arrows, some rising while others reduce in frequency as the primary frequency is increased.

The amplitude of all of these signals follows a strict mathematical relationship, called the 'sine *x* upon *x*' curve. That's shown in green on the figure. There's about a 10dB level difference between the 30MHz output and the 95MHz alias signal, for example.

That's the reason for the substantial onboard filter on the AD9850 module. It's a low-pass filter designed to cut off at 70MHz, so the majority of these aliased products do not appear at the SINB output. However, since there is no similar low pass filter on the SINA output, these alias signals are all usefully present, in full, at this pin.

As the user continues to tune the AD9850's output upwards in frequency, the 'wanted' and first 'alias' output ultimately coincide and pass each other at Fout = 62.5MHz.

A few tests using this SINA pin suggested that the usually unwanted alias frequencies above 65MHz could be obtained from the module using an external high-pass filter (HPF). That would allow the signal generator to provide useful outputs from, say, about 70MHz up to about 120MHz. With additional filtering, still higher aliasing products could be filtered out and amplified.

This permits the generator to produce signals across the 2m amateur band or across part of the 138-174MHz land mobile bands. As it turns out, useful outputs across these bands could be obtained just from using a single HPF, and the maximum tuning frequency for the signal generator was therefore set at 150MHz. Those wanting other bands or fewer aliasing outputs can modify the HPF to suit individual requirements.

Detailed circuit description

The final circuit arrangement is shown in Fig.4. While it may appear complex at first glance, this design uses remarkably few components given the range of modulation modes and coverage it provides. Some of the complexity is hidden in the software for IC1.

To enable the frequency modulation described above, the AD9850's 8-bit data port (pins D0-D7) is connected to micro IC1's PORTB digital outputs (PB0-PB7). The three 10kΩ series resistors have been added so that IC1 can be reprogrammed in-circuit (via ICSP header CON3) while IC1 is still connected to MOD1.

MOD1 is also connected to 5V power (VCC) and GND, plus the slave select (SS) and reset ($\overline{\text{RST}}$) pins, which go to digital I/Os PC4 and PD4 on IC1 respectively.

Its two output signals are fed to the HPF and switch S4, while the square wave output goes to CON4, although the signal which appears there is of limited use, as its duty cycle varies with frequency.

With switch S4 in the position shown, the lower frequency (100kHz-50MHz) signals pass through S4a, the 100nF coupling capacitor and S4b directly on to the buffer amplifier (the base of transistor Q3).

For higher-frequency signals, S4 is moved to the alternative position where the buffer amplifier is fed from the HPF output, which receives its input from the unfiltered DDS output pin.

The HPF is a standard seven-pole Chebyshev filter. Elliptical filters provide a faster pass-to-stop band cut-off, but the resulting spurious and harmonic rejection is less effective compared with the Chebyshev type. The filter was optimised to suit standard leaded components and home-made inductors.

For best performance, the coupling between the coils must be minimised. The PCB layout provides for small tin plate shields to be fitted between filter stages, a simple and effective solution.

The alternative HPF shown could potentially shift the 70-150MHz upper output range to 125-187.5MHz with appropriate software changes.

RF buffer amplifier

As noted earlier, the buffer amplifier is a robust discrete design, based on NPN transistor Q3. This is a well-known single-transistor broadband arrangement providing about 15dB gain along with good dynamic range. Gain is necessary to provide the required maximum output level for the signal generator and to compensate for the insertion loss of the Serebriakova attenuator.

Alternative discrete buffers seen in other AD9850/51 based designs lack sufficient gain across the output range and/or frequently overload with the typically higher module output levels present below 10MHz.

By contrast, this buffer amplifier's gain is relatively flat and only reduces above 50MHz. This is acceptable given the application and circuit simplicity.

If you find the 2N4427 transistor difficult to source, you may be able to find a 2N3866 instead, although the gain may reduce by several decibels.

The output of the amplifier is taken from the centre tap of autotransformer T1 and coupled to the output attenuator by a 100nF capacitor.

The attenuator consists of four identical 0/20dB switched attenuators, followed by the aforementioned 0-20dB Serebriakova attenuator, giving an overall range of 0-100dB. This allows you to adjust the output from about –93dBm to +7dBm.

As mentioned earlier, this range is limited by shielding effectiveness and RF signal leakage across the attenuator sections.

Better shielding between sections is likely to allow another 20dB fixed attenuator to be added, significantly improving its utility for small signal work. Further improvements would likely require considerable additional design efforts around the power supply and control sections.

User interface

IC1 updates the 16×2 LCD using a typical 4-bit interface. The lower four bits of PORTC on IC1 (pins 23-26) drive the four upper LCD data pins, while pins 12 and 13 (digital outputs PD6 and PD7) drive the RS and EN control lines of the LCD.

Backlight brightness is fixed using a 1kΩ resistor, with the backlight powered whenever the device is on, and trimpot VR1 provides contrast adjustment.

The Grey code pulses from the rotary encoder are sensed using IC1's PD2 and PD3 digital inputs (pins 4 and 5), while presses of the encoder's integral pushbutton and the SCAN and MODE pushbuttons (S1 and S2) are sensed using digital inputs PD0 and PD1 (pins 2 and 3).

These have internal pull-ups enabled so that they are held high when no buttons are being pressed.

As mentioned earlier, diodes D1 and D2 have been added to allow presses of three buttons to be sensed using the two available pins.

Jumper JP1 and ICSP header CON3 have been provided to allow IC1 to be re-programmed in situ. Removing JP1 prevents the programmer from trying to power the RF circuitry. CON3 has the standard Atmel 6-pin programmer pinout.

Power switching

The external power supply, nominally 12V DC, directly powers the output buffer. The buffer can operate down to 9V although harmonic distortion at full output increases by about 6dB at 9V compared to 12V.

The 12V supply is also regulated down to 5V by REG1 for the AD9850 module and the ATmega328 processor. The AD9850 module is current-hungry, so REG1 requires a heatsink.

Dissipation losses would be reduced by using a switchmode regulator, but this can introduce switching noise inside the signal generator, and could potentially modulate the output buffer output signal.

As it turns out, the metal signal generator case forms an effective heatsink for REG1, and this avoids the need for additional hardware.

The signal generator will continue to operate with a supply voltage down to 6V; however, its performance degrades significantly below 9V. By 6V, the maximum output falls by 10dB and harmonics are only suppressed by 10dB due to the reduced dynamic range in the buffer stage. So, operation at 6V is possible but not recommended.

A 'soft switch' circuit has been added to allow the use of a momentary pushbutton (S3) as a power switch.

The circuitry to provide this function is shown at the upper right of Fig.4. It was initially described by Zetex in their February 1996 Design Note 27, for use as a relay driver.

However, several problems were encountered with that design, including some curious component choices and overheating. A minor redesign and the use of a higher-gain switching transistor solved them all.

When the supply is initially connected, the voltage appears on the emitter of Q4 and the 1µF capacitor charges via the three series resistors (2.7kΩ, 1kΩ and 270kΩ). However, Q4 cannot turn on until momentary switch S3 is pressed and no current is drawn from the supply.

When S3 is pressed, current is supplied to the base of Q5, which switches it on, and it in turn sinks current from the base of PNP transistor Q4, switching it on also and bringing up its collector voltage.

Current can then flow from Q4's collector to Q5's base via the two 1kΩ series resistors, so Q5 remains on and so does Q4.

However, the 1µF capacitor discharges because Q5's collector is now being pulled low, to 0V. So if S3 is pressed again, Q5's base goes low, switching it off, and in turn switching off Q4, so the circuit is back in the initial off-state.

Part Two, next month

Next month's article will have the parts list, details of PCB assembly, case construction, programming IC1 and how to use the *RF Signal Generator*. We'll also have performance data, including spectrum plots.

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1. Gary McClellan, Programma-II synthesised signal generator, *Radio-Electronics* magazine, Aug & Sept 1981 (300kHz to 30MHz CW/AM signal generator, 10kHz tuning steps, 10-300mV output)
2. G. Baars, PE1GIC, DDS RF Signal Generator, *Elektor*, October 2003 (50Hz to 70MHz, CW/AM/FM, 1Hz to 1MHz tuning steps, 0 to -127dBm out)
3. Ian Pogson, Solid state modulated RF test oscillator, *Electronics Australia*, May 1979 (455kHz to 30MHz in four ranges, approximately 100mV output)
4. **http://lea.hamradio.si/~s53mv/dds/theory.html**
5. **www.picmicrolab.com/ad9850-pic16f-interface-parallel-data-load/**

A low-cost 3.5-inch touchscreen for the Arduino or Micromite

by
Tim Blythman

We've published many projects using 320 × 240 pixel, 2.8-inch colour touchscreens because of their low cost and ease of use. But sometimes they're a bit too small! Now we've discovered larger, higher-resolution displays that only cost a little more and are almost as easy to drive. Where do you get them . . . and how do you use them with an Arduino or Micromite?

While we were working on the *Diode Curve Plotter* project, published in the March 2020 issue, we thought that it would be nice to have a larger display area for the graphs.

The 5-inch (13cm) display that we've used with Explore-100-based projects is fantastic – but it's quite expensive and a bit larger than is really required for many projects.

There is a similar 4.3-inch (11cm) screen, but it's hardly any cheaper than the 5-inch display. Also, both the 4.3-inch and 5-inch screens have another problem: they use a parallel interface, which takes up a lot of I/O pins, and the regular Micromite doesn't have support for parallel displays. You need to use the Micromite Plus, which means soldering an SMD microcontroller.

What we really wanted was a larger, higher-resolution screen that uses the same serial control interface as the 2.8-inch (7cm) ILI9341-based screens that have been so popular. That would give us more screen real estate and more pixels, without using up any more I/O pins – and that's just what we found.

We have been aware of the existence of 3.2-inch (8cm) and 3.5-inch (9cm) touchscreen modules for some time; but in the past, all the ones we'd seen had a parallel interface.

That's good for providing a fast update rate, but it requires a micro with a parallel interface and plenty of pins to use efficiently.

So we went searching for similar serial-controlled screens, and we found two AliExpress vendors offering just that (see: **www.aliexpress.com/item//32954128438.html** and **www.aliexpress.com/item//32954240862.html**). We bought one from each to test.

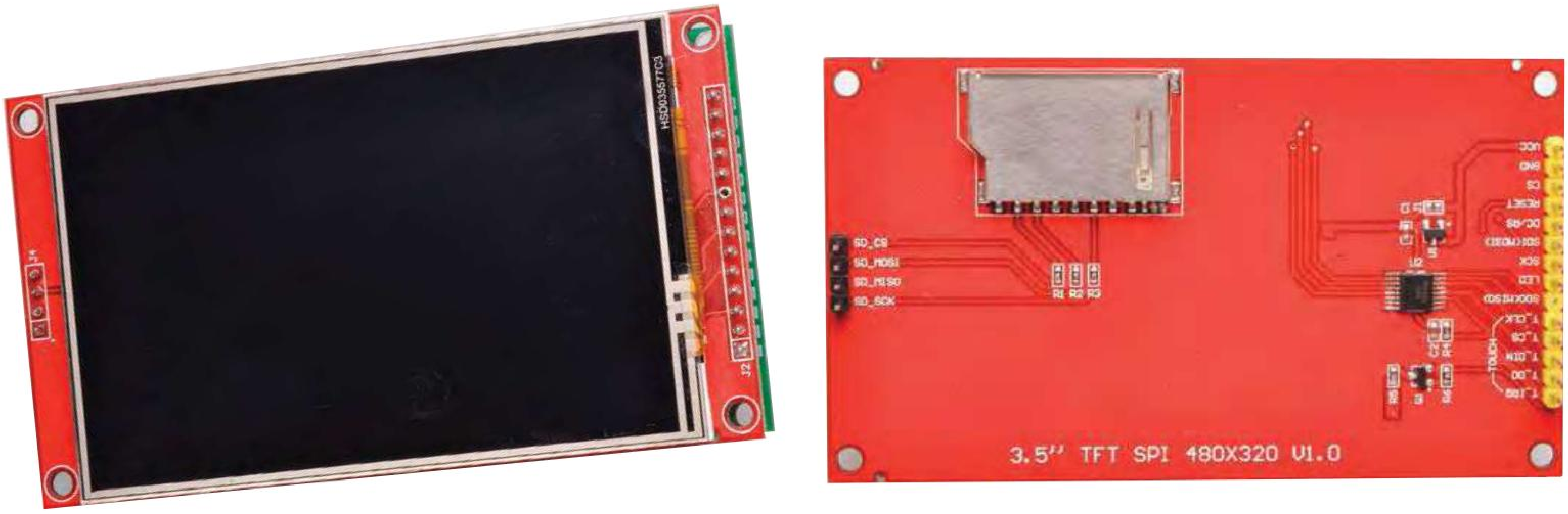
There are several different variants of this type of display around, with different connectors and interfaces, but all use 0.1-inch (2.54mm) pitch header pins to connect to the controller board. Many sellers indicated that they use the ILI9488 controller IC, although, as we found out later, this is not always the case.

They all come with either a full-size SD or microSD socket onboard, and many have a resistive touch panel too. We particularly wanted to get the touchscreen variants since that obviates the need to fit any buttons or other controls in most cases.

Once we got the screens, it took quite a bit of effort to get them working (for reasons we'll explain later), but we got there in the end. Our software and source code is available so that you can do this too – visit the downloads link of the June 2020 page of the *PE* website.

We also decided to try out some other similar screens, one from Altronics (because it was easy to get) and another which is designed to plug straight into an Arduino, since that one is really easy to get up and running if Arduino is your platform of choice.

This article assumes that you are familiar with either the Arduino Integrated Development Environment (IDE), or Micromite BASIC and the various methods of uploading MMBasic code to a Micromite.



Contestant #1: we recommend that you use this 3.5-inch display panel as it works with either a Micromite or Arduino (once you build our breakout board). We cut off the pin which is now missing, as it was causing a conflict between the touch and display controllers, but that is no longer necessary with the revised breakout board we present in this article.

If you are not, we suggest that you try working on simpler projects with these platforms before diving into this one.

We have designed a small breakout board to connect the 'universal' 3.5-inch serial touchscreen (ie, the one that does not come as a 'shield') to an Arduino.

We'll describe this board below. This breakout board also works with the 2.8-inch touchscreen that we've used so often in the past in the *Micromite LCD BackPack*.

Contestant #1: 3.5-inch serial touchscreen

The 3.5-inch serial touchscreens we sourced look very similar to the 2.8-inch touchscreen used in the very popular *Micromite LCD BackPack* project (*PE*, May 2017).

The screen is not only bigger, but it also has a substantially higher resolution, at 480 × 320 pixels (0.15MP) compared to 320 × 240 pixels (0.07MP). So it has exactly twice as many pixels.

As you would expect, given the extra 0.7 inches (20mm) of diagonal screen size, it is slightly larger, and the PCB is slightly longer, so the two pin headers on the board are around 13mm further along than in the smaller LCD. The mechanical mounting holes are also arranged differently.

Otherwise, the main 14-pin interface header appears identical, and the pins are marked with the same designations. Like the 2.8-inch display, you can get these with or without the touch panel. The price difference is small, so it's worthwhile to get the one that has it.

The main appeal of this unit is that it can plug into the existing *Micromite BackPack* and even if you're using it with an Arduino Uno, it won't take up all that many digital I/O pins, so you will still have plenty left for other tasks.

It's controlled using two SPI interfaces, one for the display and one for the touch panel, although you can drive both from a single set of SPI pins on the micro. Like the 2.8-inch LCD used with the *Micromite BackPack*, the full-size SD card socket is accessible from one of the long edges of the PCB.

To simplify our experiments on these displays with Arduino boards, we designed the aforementioned breakout PCB that suits both the 2.8-inch 320 × 240 display and the 3.5-inch 480 × 320 display.

The instructions for assembling this breakout board can be found below. If you have one of these displays and an Arduino board, you might want to build this board before reading the following usage instructions.

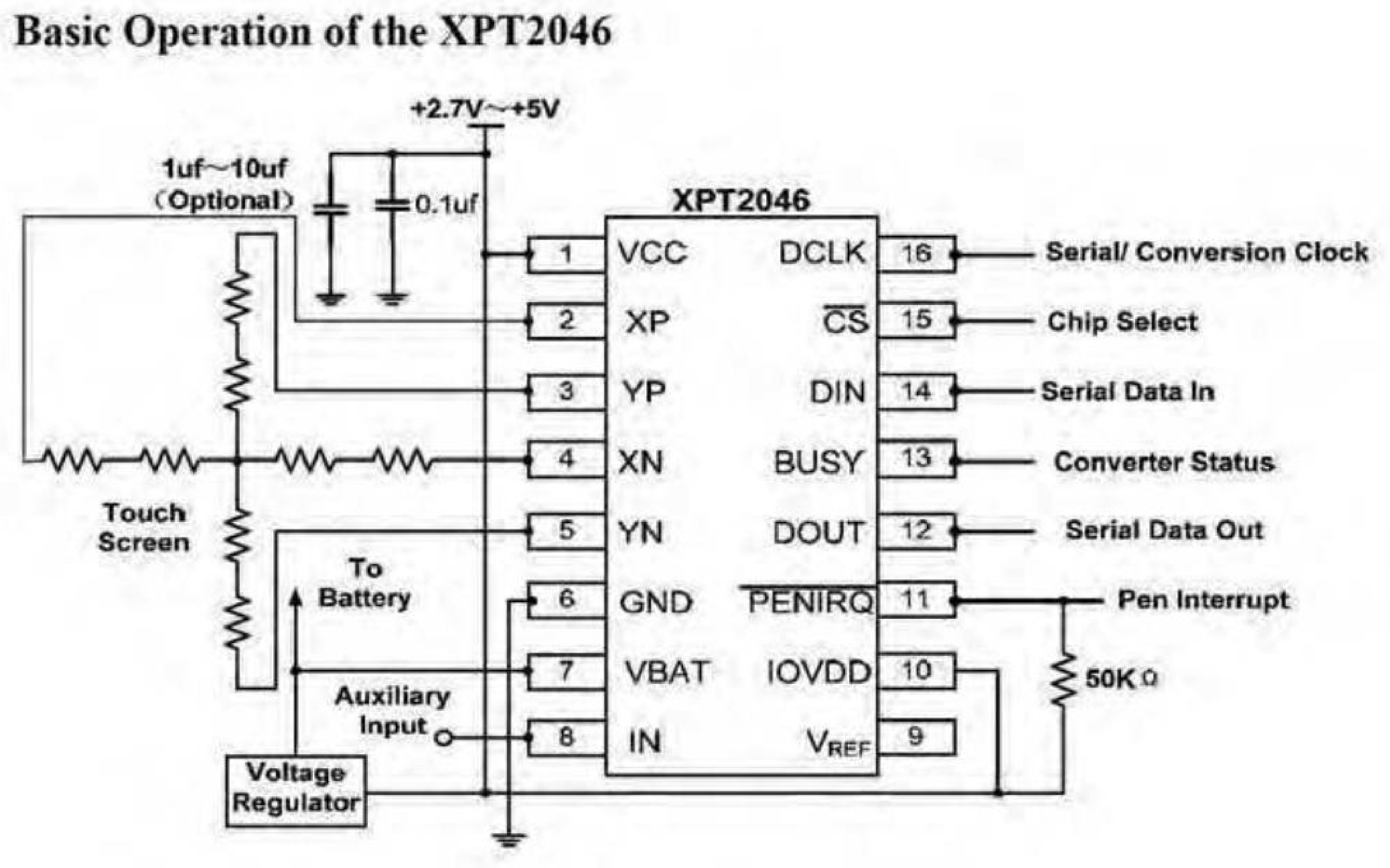


Fig.1: this excerpt from the XPT2046 datasheet shows a typical circuit for the chip and demonstrates how the touch panel can be viewed as a variable resistor network.

Getting it working with an Arduino

The prevalence of Arduino libraries meant we started our breakout board tests using an Arduino Uno. After a few attempts, we found a library that was able to drive the display; it can be found at **https://github.com/jaretburkett/ILI9488** (see Fig.4)

We had to change the pin assignments in the example sketch, named **graphicstest**, to the following:

```
#define TFT_CS    10
#define TFT_DC    9
#define TFT_LED   -1
#define TFT_RST   8
```

There is no pin '–1', but this value can't be empty, so a value of –1 is used because this is ignored by digitalWrite commands since it is an invalid pin number, and therefore has no effect. On our board, the LED pin is hardwired to the 5V rail, forcing the LCD backlight on, to save as many pins as possible for other uses.

Interestingly, this library was modified from another library designed for the ILI9341 controller, which is what is in the 2.8-inch displays. It provides a low-level interface to the **Adafruit_GFX** library. This library provides common, high-level functions like drawing shapes and text to displays.

Adafruit has developed a good number of display boards and modules (many of which are now appearing as clones), and they have excellent support for their displays. Their libraries are a great resource for getting many displays running.

While it's nice to have some library code that works, we wanted to know how to control these displays at a much lower level and get an understanding of their operation.

To see what sets the larger ILI9488-based displays apart from the smaller ILI9341 ones, we added some code to the libraries to print out (to the serial monitor) what commands and text were being sent to the board, formatting this output as commands which could be pasted directly into the Arduino IDE. This is shown in Screen1.

This showed us the required initialisation sequence for the display controller. We then checked the ILI9488 datasheet (**https://bit.ly/pe-jun20-ILI9488**) and confirmed that the commands that were being issued were appropriate.

There are a few commands that require a delay after they are sent, to allow the controller to process the data, so we needed to know when these should occur. We could then build a working sketch from scratch to drive the display.

Since the ILI9488's drawing (as opposed to initialisation) commands are practically identical to those for the ILI9341, once it's initialised, the process of drawing on the screen becomes quite straightforward.

Although the datasheet hints that a 16-bit colour mode (as used with the ILI9341) is available, it doesn't appear to work in SPI mode on the ILI9488, so we had to modify the code to produce 24-bit colour values.

We've distilled all this code down to just the essentials and put it in a demo sketch titled **SPI_320 × 480_display_demo**. This demonstrates drawing on the screen in all four orientations, including region fills, text and lines made of individual pixels.

Micromite support

We were then able to translate this Arduino sketch into working Micromite BASIC (MMBasic) code. We had to do a search and replace to change Arduino's '0x' hexadecimal prefix with '&H' to suit BASIC, as well as changing the function definitions to subroutines, among other amendments.

The demo BASIC file is called **SPI_320x480_display_demo.bas**

For the Micromite, the font data is embedded as a CFUNCTION. While this directive is usually used to store machine code, it can be used to store any binary data for MMBasic, and is a more compact way of doing this than DATA statements. Some of the display routines have been modified to work with larger arrays of data, as the SPI interface works more quickly with arrays than individual values.

Before this improvement, clearing the screen took nearly a minute.

This display code would be an ideal candidate for a CFUNCTION, as that would allow it to work a lot quicker, but the intention here is to demonstrate what is possible, and also to show how the interface works.

We expect readers will have an easier time understanding the BASIC code than the equivalent C code, even if the C code would be substantially faster.

If you are using the Micromite Plus BackPack, use the source files with the 'MMplus' suffix at the end. The SPI2 peripheral is used for display communications on the Micromite Plus, so you may need to run an 'OPTION … DISABLE' command if there are any other peripherals using SPI2 before the display code will work.

Similarly, on the regular Micromite, any OPTIONs that lock the SPI bus may need to be disabled before using our sample programs.

Note that we have not designed a breakout board to interface this screen to a Micromite.

That's because it can be plugged straight into the 14-pin header socket on a *Micromite LCD BackPack* (V1 or V2). The mounting holes don't line up, but we're sure that our readers will figure out clever ways to mount these boards successfully.

Touch interface

One of the great features of these displays is the touch interface. A quick inspection shows that like the 2.8-inch touchscreen we're familiar with, the 3.5-inch screen uses the same XPT2046 touch controller IC and the connections appear to be practically identical.

We even found some schematics which indicated that this was the case.

The XPT2046 touch controller is effectively a multi-channel 12-bit analogue-to-digital converter (ADC), which is intended to be connected to a four-wire touch panel. It can drive its analogue pins as needed to supply a voltage difference across the touch surface. Fig.1 shows a typical connection to the XPT2046 IC.

An 8-bit command is sent to the XPT2046 over the SPI bus, which sets up the drivers and ADC multiplexer, and starts an ADC conversion. This conversion is clocked (timed) by the following pulses on the SPI SCK clock line.

Twelve bits of data are read out from the chip, along with four zero bits (for a total of 16 bits or two bytes), after which the touch controller is ready for another conversion.

So this is all pretty straightforward, and we had code which worked with the 2.8-inch touch panels, but it would not work with the 3.5-inch panels.

We tried many different approaches to solve this, including probing the lines going to the touch panel itself, and ultimately we discovered that the problem was due to the LCD controller and touch controller sharing one MISO (master in slave out) line.

The display controller should not be driving this pin when its $\overline{\text{CS}}$ (chip select) line is high, as this is how multiple devices share an SPI bus.

The touch controller correctly leaves its MISO pin floating when its $\overline{\text{CS}}$ line is high. But the LCD controller appeared to be driving MISO all the time, and this was preventing the touch controller from pulling it high, resulting in the micro receiving all zeros.

The fix was easy; we disconnected the LCD controller's MISO line entirely, as it is not needed since we never read data back from the LCD controller. Then, everything worked like a charm.

The final Arduino shield design has a jumper to disconnect this pin from the SPI bus, so you should be able to get the touch controller working simply by leaving it open.

Once we got the touch interface working, we wrote a few more sample programs (both Arduino sketches and Micromite BASIC). One of these is a basic demo and the other provides test and calibration features.

They are named **SPI_3.5_inch_TFT_shield_demo_wth_touch.bas** and **SPI_3.5_inch_TFT_touch_calibration.bas**, with the Micromite Plus equivalents having the same names but with 'MMplus' at the end.

SD card support

Like the smaller 2.8-inch display modules, the 3.5-inch displays also have an SD card socket connected to a separate set of pins via 1kΩ resistors. As there is no direct connection to these pins on the *Micromite* or *Micromite Plus BackPack*, the only way to access the SD card with these boards is by adding jumper lead connections.

Our Arduino breakout board has headers to make connections to the SD pins for both the 2.8-inch and 3.5-inch displays. And since the display module has nothing to prevent 5V being fed into the SD card pins, we have designed the breakout board to do all the level conversion, as this is also needed for the display and touch controllers.

The Arduino IDE provides a basic SD interface library, and we tried the **listfiles** example from **Files -> Examples -> SD**

Our design uses digital pin 6 as the SD card chip select line, so we simply changed one line in the **listfiles** sketch to use the correct $\overline{\text{CS}}$ pin like this:

```
if (!SD.begin(6)) {
```

We were then able to retrieve a list of the files from an SD card plugged into the socket on the display. Our breakout board can also be used to read data from SD cards.

Verdict

Now that we've figured out how to drive it and use the touch panel, this display is an excellent choice, especially for use with Arduino boards.

And since it can also be used with both the Arduino and Micromite boards, we hope to use it more in the future. The SPI interface means that the pin usage is minimal.

We'll need to come up with some CFUNCTIONs if we hope to use this display with the Micromite, as the BASIC interface is quite slow.

But the BASIC code is certainly a good starting point, and may be sufficient for some applications.

Before we get to the assembly of the breakout board for this display, let's take a look at a couple of other candidates that we evaluated.

Contestant #2: Altronics Z-0575

The next board is a 3.2-inch LCD screen which does not have a touch panel. It's designed to plug into an Arduino Mega, and it is available from Altronics, Cat Z6527 (**www.altronics.com.au/p/z6527**) as well as other sources. Altronics say that it has an ILI9481 controller IC, and they appear to be correct, as it works with Arduino libraries designed for that controller chip.

This display has a 16-bit parallel interface and is designed to work with contiguous port pins on the Arduino Mega, meaning that, in theory, it will be capable of very fast communication using direct port writes.

But that also makes it virtually impossible to use with a regular Arduino or a Micromite.

Its header layout is interesting. There is a long 2×18 pin header at one end, which suits the large header block at one end of the Mega.

There is also a small 2-pin header which connects to the 3.3V and $\overline{\text{RESET}}$ pins at the other end of the Mega. This requires the display to rest on the USB socket for support while blocking practically all of the other pins.

Interestingly, the full-size SD card socket is deep inside the board outline and is not accessible while the board is attached to a Mega.

On the same side as the SD card socket are three small SSOP ICs (which are responsible for converting between the Arduino's 5V logic levels and the display's 3.3V) as well as a capacitor, resistor, voltage regulator and an unpopulated SOIC-8 footprint.

The specification sheet notes that the display will work from 3.3V to 5.5V, so it might also be suitable for 3.3V boards such as the Arduino Due, although we have not tried this.

On the front of the display is a tactile pushbutton, which is connected between the GND and $\overline{\text{RESET}}$ pins on the Mega board, so that pressing it resets the microcontroller on the Mega board.

Getting it working

Altronics provide a good amount of sample code, which can be downloaded from the downloads tab of the product page linked above. This download includes manuals, libraries and images of sample display output.

We used an Arduino Mega to test it, mainly because most of the other micro boards we had on hand didn't have enough I/O pins to drive it – you need 20 I/O pins just to run the display, and even if you have that many free, it would be fiddly to wire it up using jumper leads (see Fig.2).

The board is effectively a shield for the Mega and directly plugs in on top. While easy to insert, the large header is hard to remove, and we found we had to take care detaching the shield by wiggling the display to gently ease the pins out so that they don't catch and bend.

We extracted the **Arduino Demo_Mega2560** folder from the zip file and copied the contents of the **Arduino Demo_Mega2560\Install libraries** folder to the Arduino libraries folder. In Windows 10, our libraries folder is at: **Documents\Arduino\libraries** – we then had a libraries folder – see Fig.3.

It appears these libraries are adapted from those that can be downloaded from **www.rinkydinkelectronics.com/library.php** – this is a handy website which also offers fonts that can be used with graphical LCDs.

We restarted the Arduino IDE for it to recognise the newly copied libraries.

The example sketches can be found in the **Arduino Demo_Mega2560** folder. The **Example01-UTFT_Demo_480x320** sketch cycles through a few demonstration patterns.

The other sample sketches demonstrate fonts, buttons and bitmaps, although, as noted, this display does not have a touch panel, so it was not possible to test the button sketches properly.

SD card slot

As we mentioned, there is an SD card slot tucked under the board. This can be handy, as it allows large images, graphics or icons to be stored on an SD card instead of taking up valuable Flash memory in the microcontroller.

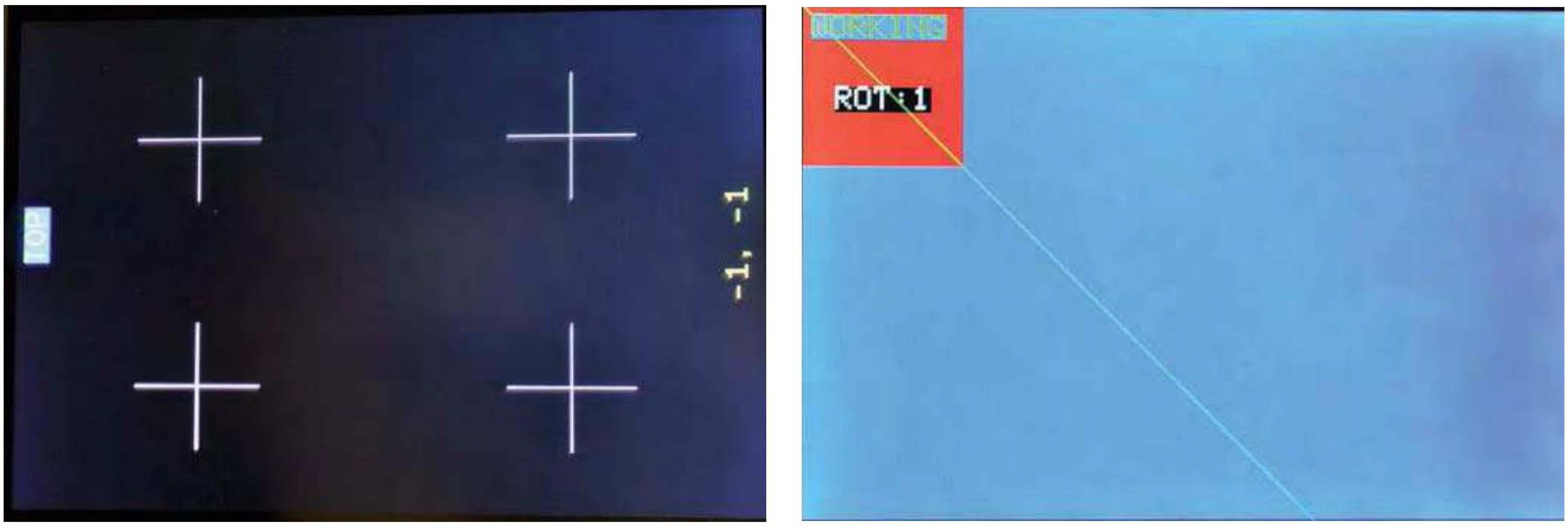
Once again, we tested it with the **listfiles** example from **Files -> Examples -> SD**.

The pin map on the diagram does not have numbered pins, but we were able to ascertain that the SD card's $\overline{\text{CS}}$ pin is connected to pin 53 on the Mega. Thus, we needed to change the line:

```
if (!SD.begin(4)) {
```

to read

```
if (!SD.begin(53)) {
```



These are the test patterns you will see when you run our sample programs. The shadowing (particularly on the right-hand photo) is an artefact from photography – this is almost invisible with the naked eye.

31
33
35
37
39
41
43
45
47
49
51
53
GND

Contestant #2: this display board lacks a touch panel but sits neatly over the top of an Arduino Mega. The tactile switch resets the connected microcontroller when pressed.

before compiling and uploading the sketch. It then worked, showing a listing of all the files on an inserted SD card, so the SD card slot on this board works as expected.

The unpopulated footprint noted earlier is designed to be fitted with a Flash memory IC. It too uses the SPI bus, and the specification sheet says it uses the Mega's pin 45 as its $\overline{\text{CS}}$ (chip select) line.

There is no further information on how this should be used, although we would not be surprised if the footprint matches many of the commonly available Flash memory ICs.

In summary, this display is easy to get, looks good and works well with the provided libraries.

The lack of a touch panel limits its utility somewhat, as does the awkward placement of the SD card slot. Being slightly smaller than the other two screens, but with a similar pixel count, it does offer a slightly higher pixel density.

Contestant #3: 3.5-inch with Arduino pinout

The final display we tried is a 3.5-inch touchscreen with a standard Arduino shield pinout, and it gives a very tidy result when plugged into an Arduino Uno (see above).

The display's PCB sits flush with the USB socket on the Arduino board, and the microSD card slot fits neatly next to that USB socket. On the back of the PCB, along with the microSD card slot, there are two SSOP ICs (presumably for level conversion) and an unpopulated SOIC footprint.

The SD card and SOIC-8 footprint appear to be connected directly to the board's I/O pins and not via the level converter ICs.

The PCB itself is only marginally wider and longer than the display. So when combined with an Arduino Uno, it's quite compact. But because this display uses an 8-bit parallel interface, it uses up many of the available pins.

With the Uno, only a single analog pin and the serial communication pins are left free. That rather limits the utility of the combination!

So you'd need to use it with a Mega in practical applications, which rather negates its compactness advantage, and also would require significant software changes that would slow it down.

The board is marked with 'mcufriend' branding, and this hint led us to find some helpful tools to work with the module.

We tried code designed to interface to the ILI9488 controller in parallel mode (which it supposedly used), but that didn't work. Since the seller advised that the display could have one of a few different controller ICs, we decided to figure out which one it actually had.

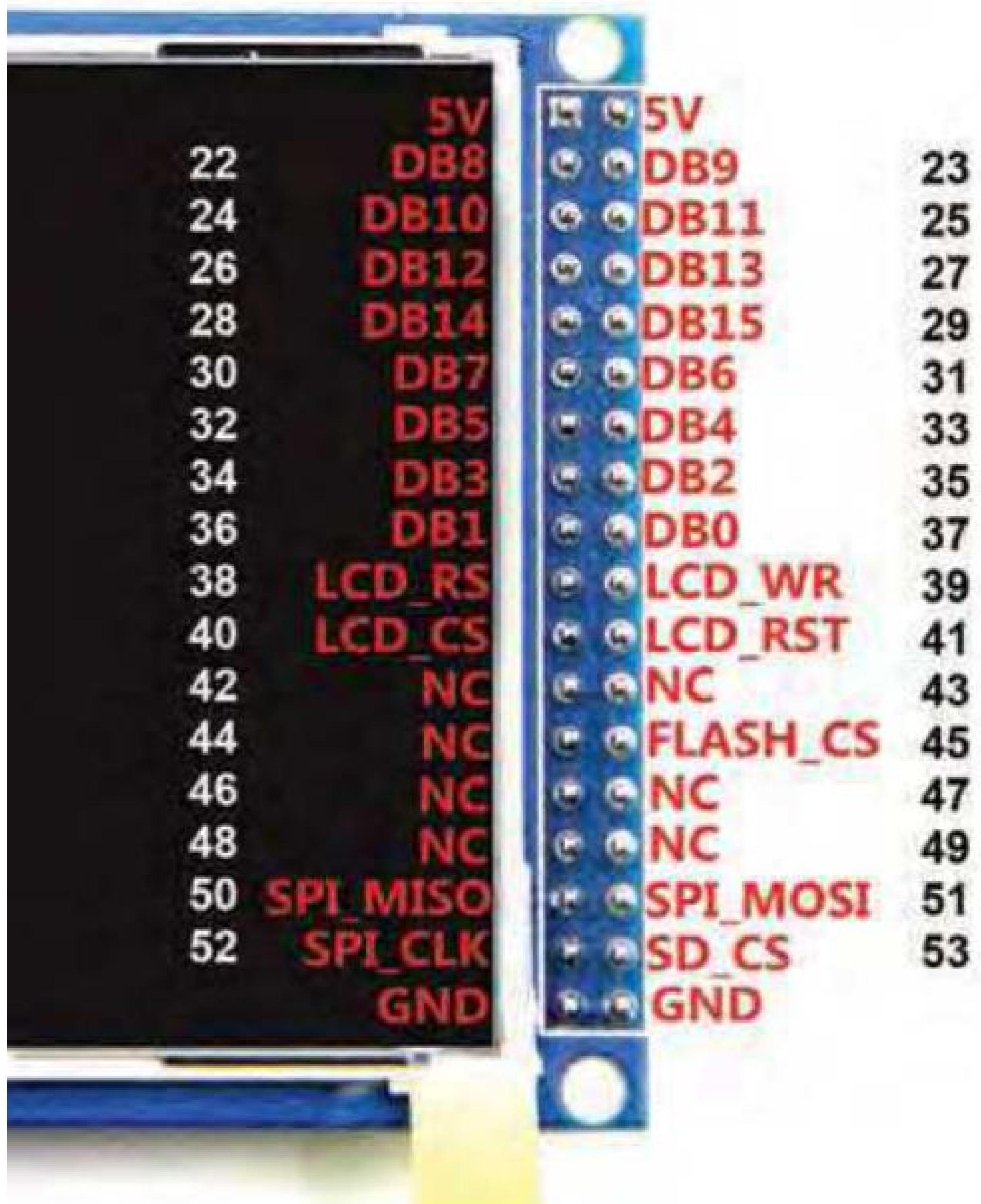


Fig.2: a pin map for the Altronics display shield, designed to plug into an Arduino Mega. We have added the Mega pin numbers for clarity, although these are not needed for the direct port writes used in the library code.

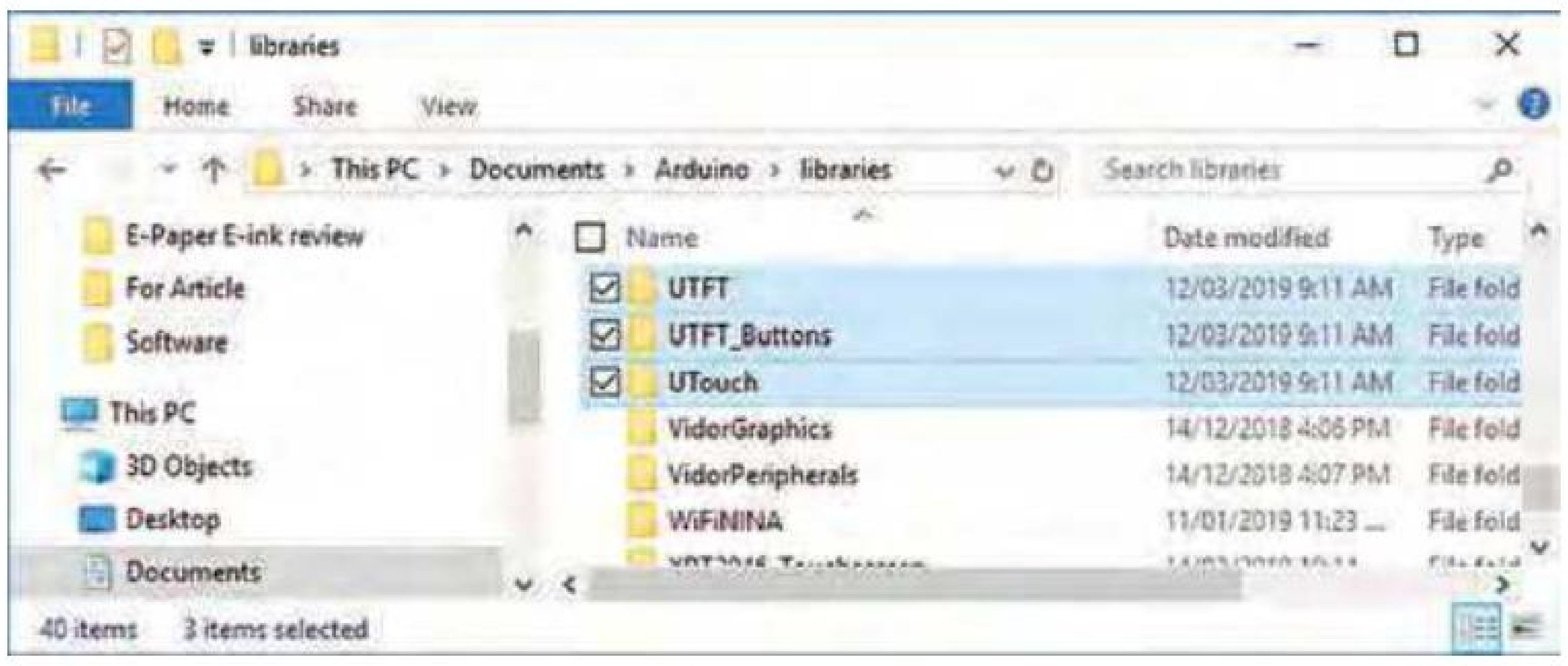
There is an excellent resource at **https://bit.ly/pe-jun20-shield** – this is a tool designed to help identify and operate these shield-type displays.

At the time of writing, the most recent update to this tool/library was only four days prior, so it appears that it is continually being updated. It also requires the **Adafruit_GFX** library, and it can identify and control a large number of different displays.

Both the **Adafruit_GFX** and **MCUFRIEND_kbv** libraries can be found and installed from the Arduino IDE's library manager. Screen2 shows how you can find and install these library dependencies using the Arduino Library Manager.

We opened and ran the **graphictest_kbv** sketch from the **File -> Examples -> MCUFRIEND_kbv -> graphictest_kbv** menu. This displays some information to the serial monitor at 9600 baud, including an identification code which is read from the board. In our case, the code was 0x6814.

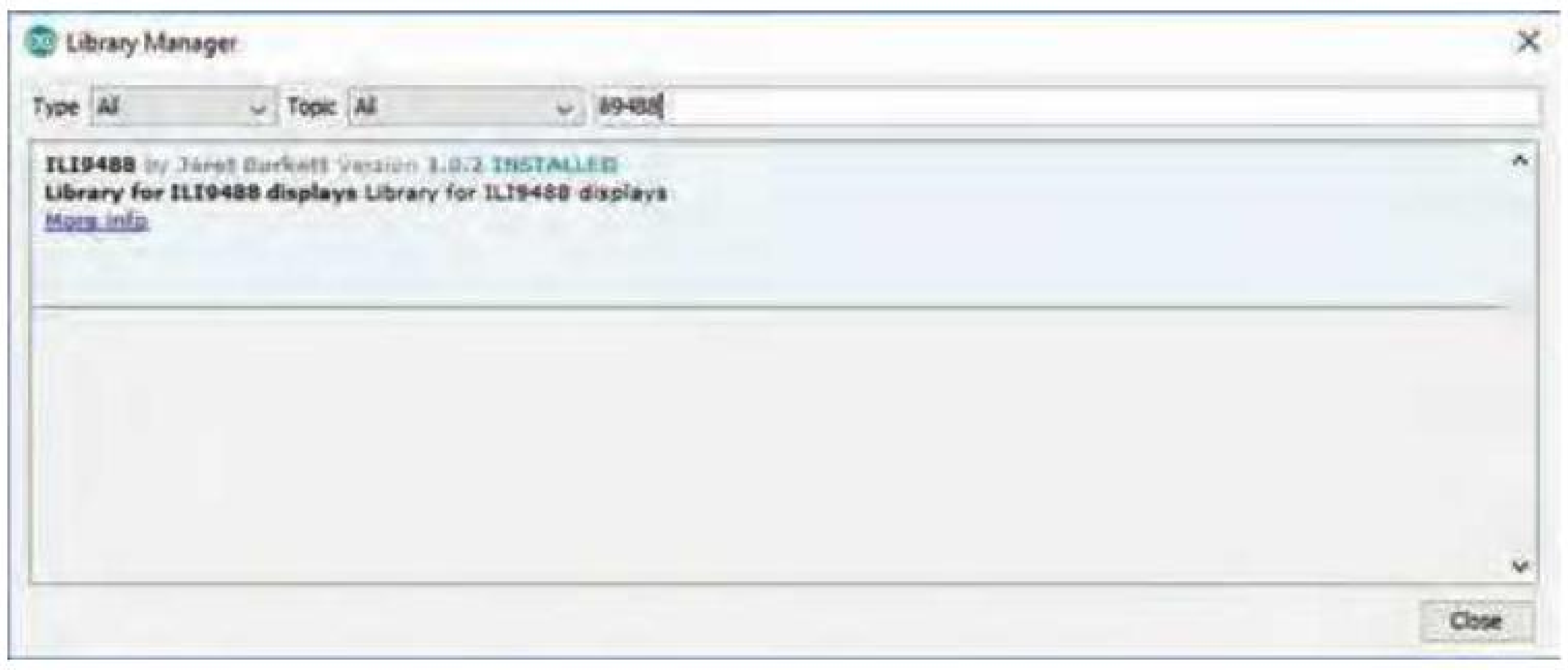
According to the **MCUFRIEND_kbv.cpp** file in the library, this suggests that the controller is an RM68140, which is similar to the ILI9488 but has a different initialisation sequence.



	Name	Date modified	Type
☑	UTFT	12/03/2019 9:11 AM	File fold
☑	UTFT_Buttons	12/03/2019 9:11 AM	File fold
☑	UTouch	12/03/2019 9:11 AM	File fold
	VidorGraphics	14/12/2018 4:06 PM	File fold
	VidorPeripherals	14/12/2018 4:07 PM	File fold
	WiFiNINA	11/01/2019 11:23 ...	File fold

40 items 3 items selected

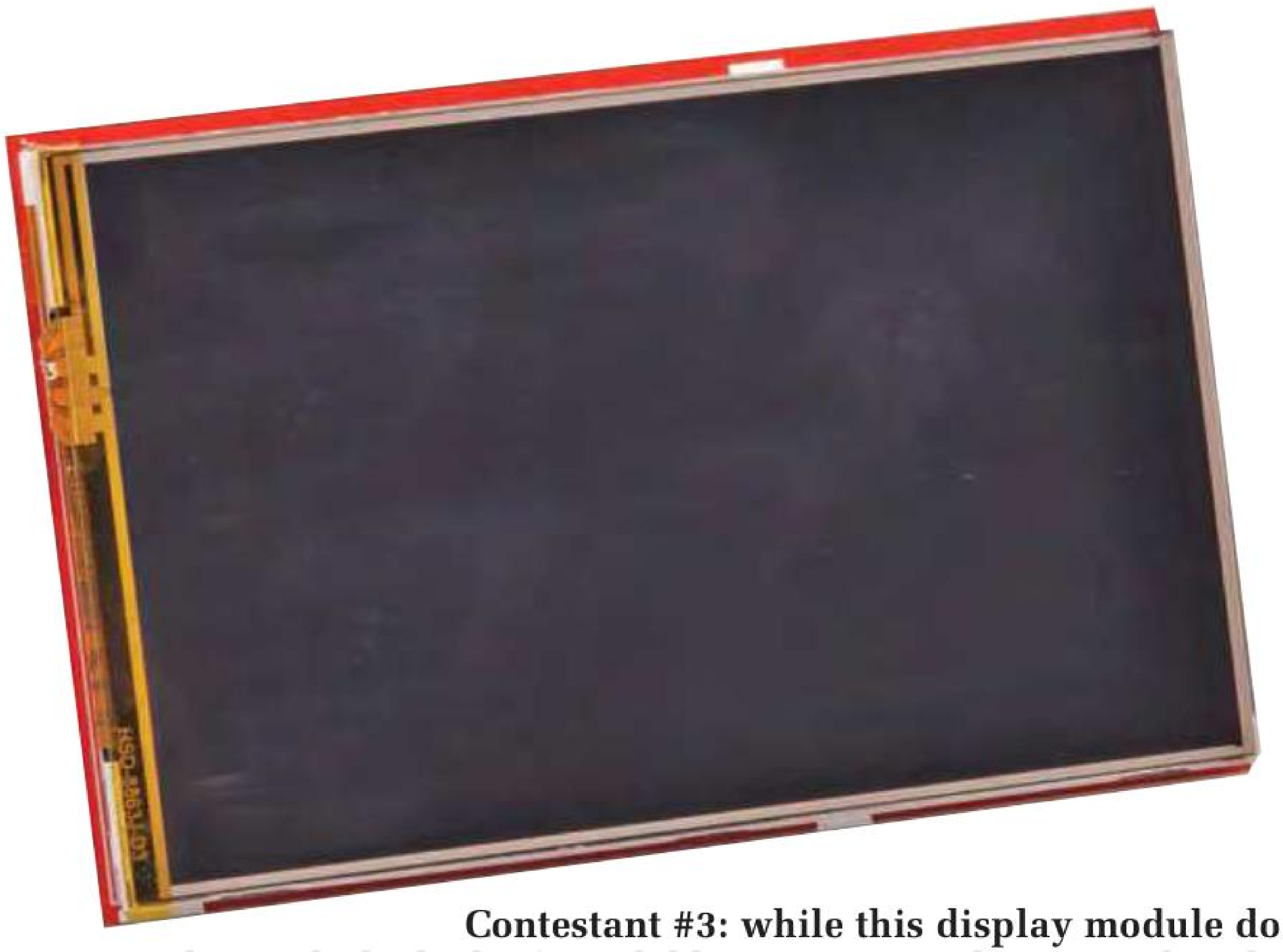
Fig.3: after unzipping the Z6527 resources from the Altronics website, the library files should look like this. The three selected folders starting with 'U' are the ones being copied.

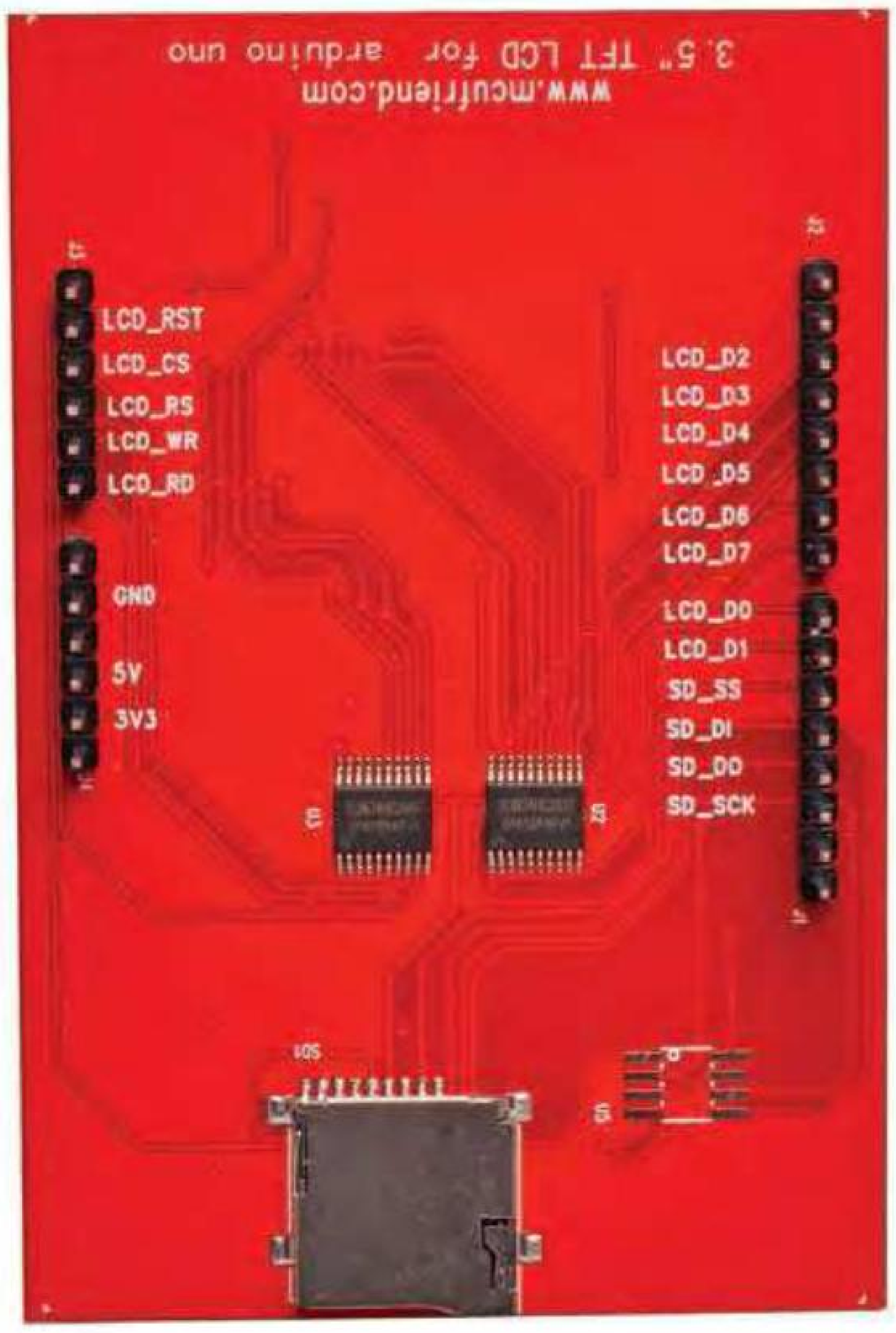


i9488

ILI9488 by Jaret Burkett Version 1.0.2 INSTALLED
Library for ILI9488 displays Library for ILI9488 displays

Fig.4: the ILI9488 library from https://github.com/jaretburkett/ILI9488 **can be installed using the Arduino Library Manager by searching for ili9488.**





Contestant #3: while this display module does have a touch panel, the lack of available spare pins when paired with an Uno means that it may not be very useful, as the Arduino cannot easily be connected to any other device.

In our case, this demo code initialised the display and drew various test patterns, indicating this sketch is capable of working with this display board.

We took a look at the RM68140 data sheet but opted for a sneaky trick to work out the initialisation sequence, without having to read it in depth.

We embedded some extra code into the library mentioned above to see what commands and data were being issued to the display, then copied these back to our sketch. This resulted in a working example sketch, named **8bit_320x480_display_demo**

Our June 2020 *PE* download package also has a cut-down version of the **MCUFRIEND_kbv** library demo sketch. You will note that the sketch produces similar results to our example, but is much larger due to the library having many features that aren't used.

Our sample code is designed to work on an Arduino Uno board. Differing port and pin configurations means it will not work on other Arduino boards; it depends on direct port access for speed. The sketch includes some code that should work on other Arduino boards, but it is very slow and has been commented out for simplicity.

Touch panel

The touch panel on this type of display is a simple four-wire resistive type. It doesn't even have a dedicated controller IC, but instead, connects directly to the Arduino analog I/O pins.

You can determine the touch location setting of one of these pins to 5V (high), another to GND (low), and then performing an ADC read on either of the two remaining pins. The resulting value indicates the relative position of the touch in the X or Y axis.

So the touch panel effectively behaves as a two-dimensional potentiometer, with the 'wiper' actually being the point being touched.

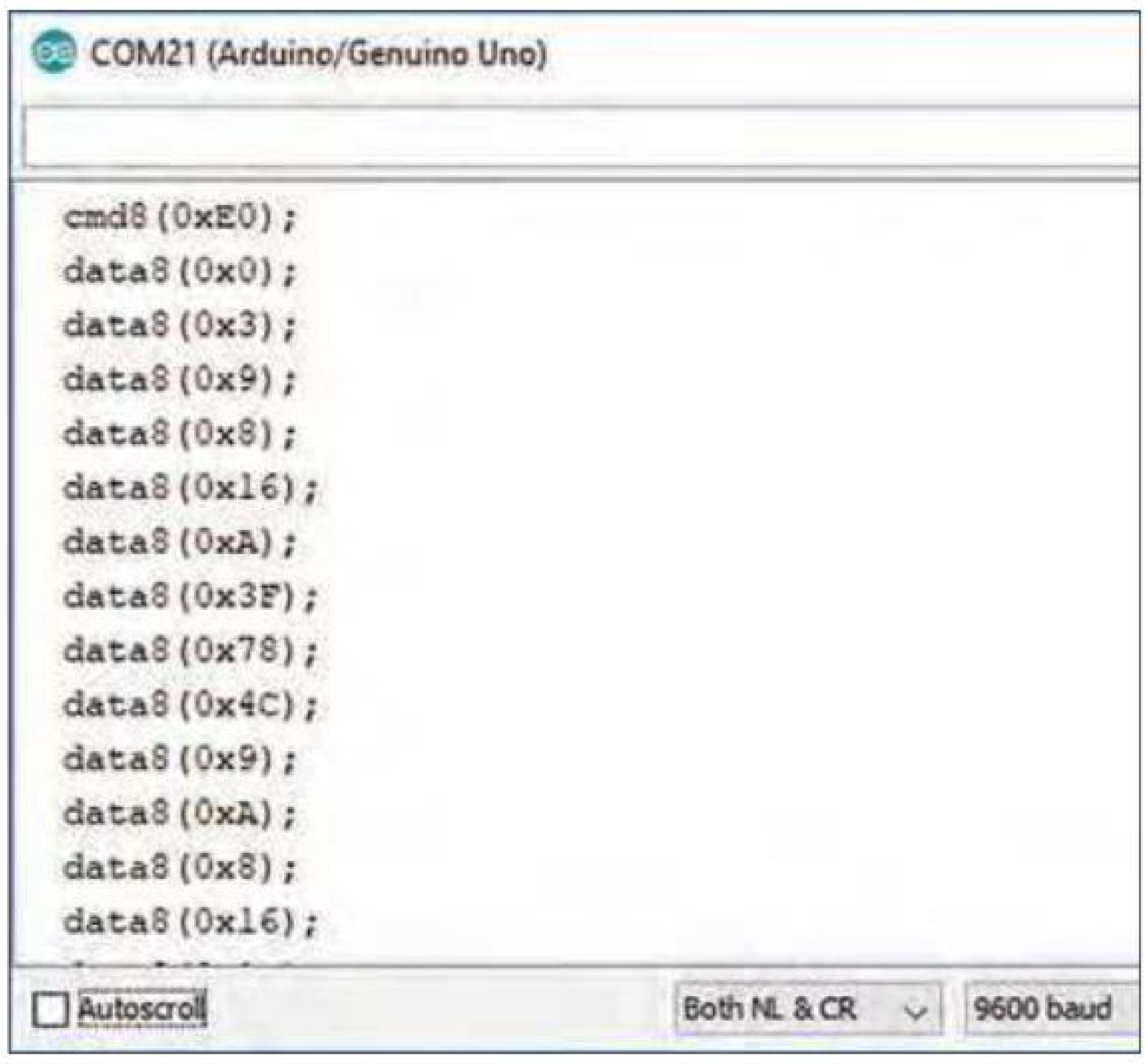
As two of the wires are connected to the horizontal edges and two to the vertical edges, the location in two dimensions can be found by performing two readings as described above, but changing which pins are driven and which are sampled.

On this panel, the touch panel is connected to pins D6, D7, A1 and A2. Interestingly, all of these pins are also used for driving the display, so this is a very busy shield. This does not interfere with their touch functions.

We've written a basic sketch that reads from the touch panel and displays the raw ADC readings on the screen. It's called **8bit_320x480_touch_demo**

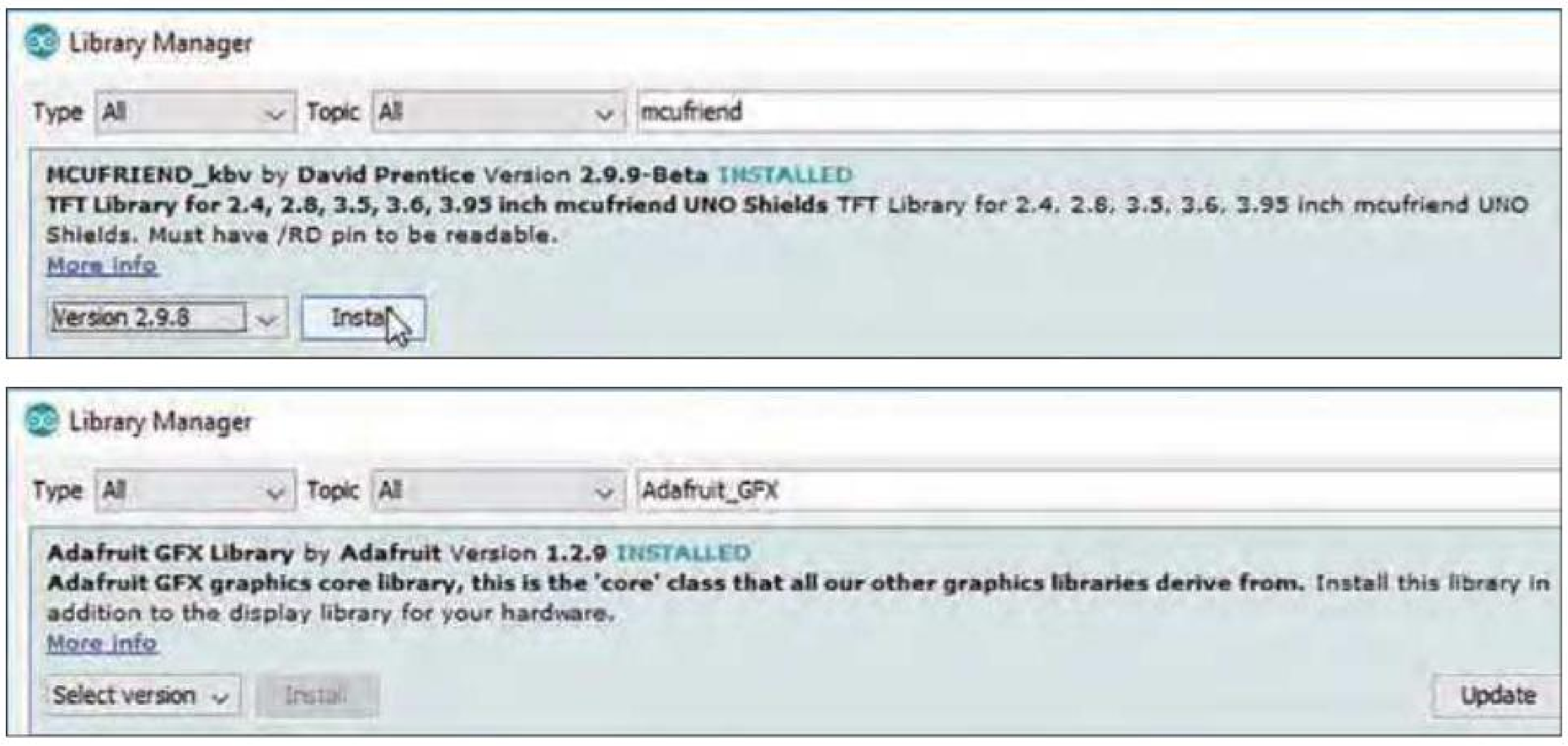
These ADC readings would need to be converted into display coordinates to implement a functional interactive touch interface, which in turn would require a calibration procedure, to account for differences in displays.

We've also provided a sketch called **8bit_320x480_touch_calibration**, which shows the basics of how to do this conversion and gives you a starting point for doing it.



```
cmd8(0xE0);
data8(0x0);
data8(0x3);
data8(0x9);
data8(0x8);
data8(0x16);
data8(0xA);
data8(0x3F);
data8(0x78);
data8(0x4C);
data8(0x9);
data8(0xA);
data8(0x8);
data8(0x16);
```

Screen1: this Arduino code was generated by software running on the Arduino itself, after we added carefully crafted debugging code to the library which was able to initialise the LCD controller successfully.



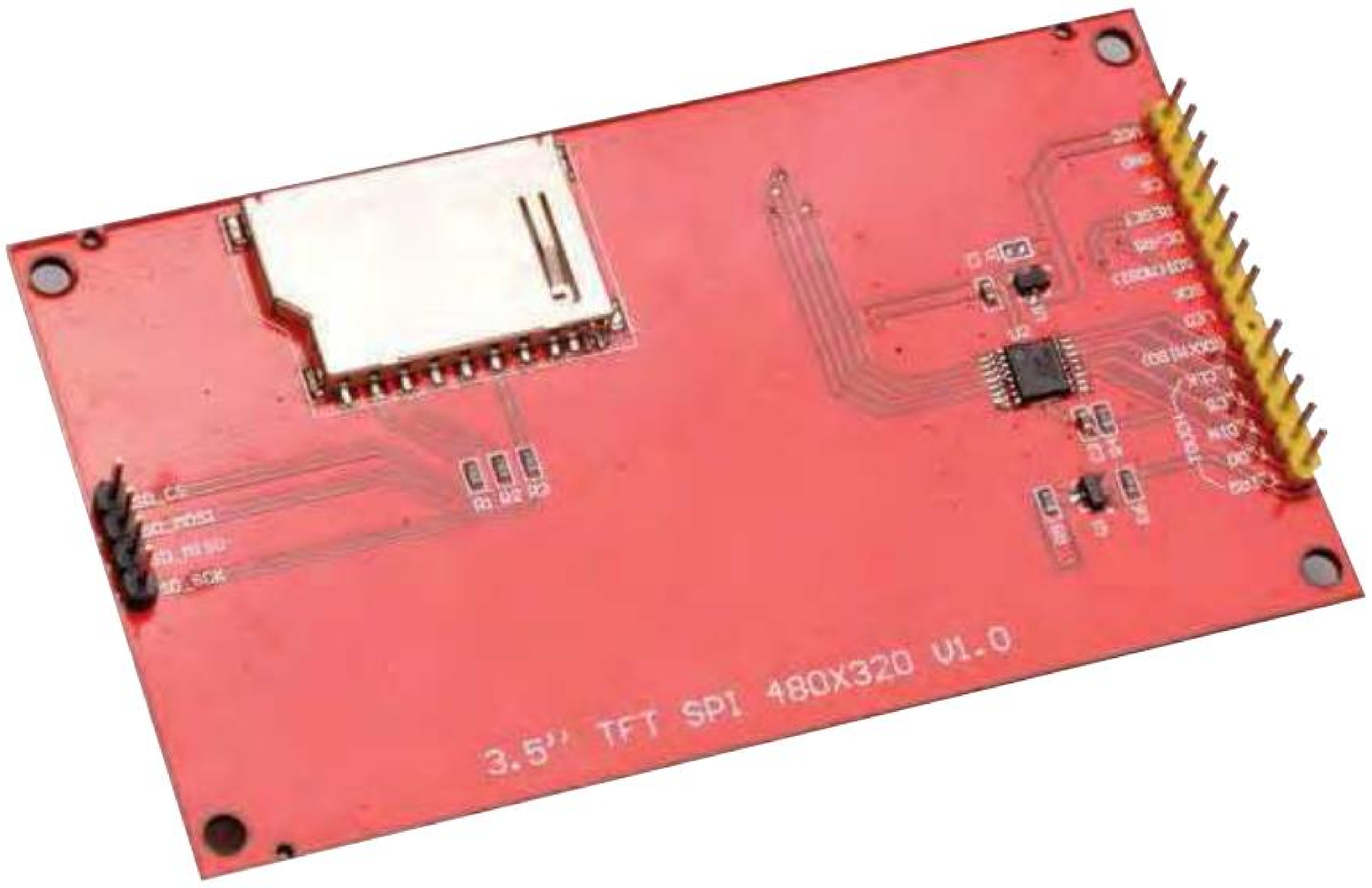
Type: All Topic: All mcufriend

MCUFRIEND_kbv by **David Prentice** Version **2.9.9-Beta** INSTALLED
TFT Library for 2.4, 2.8, 3.5, 3.6, 3.95 inch mcufriend UNO Shields TFT Library for 2.4, 2.8, 3.5, 3.6, 3.95 inch mcufriend UNO Shields. Must have /RD pin to be readable.

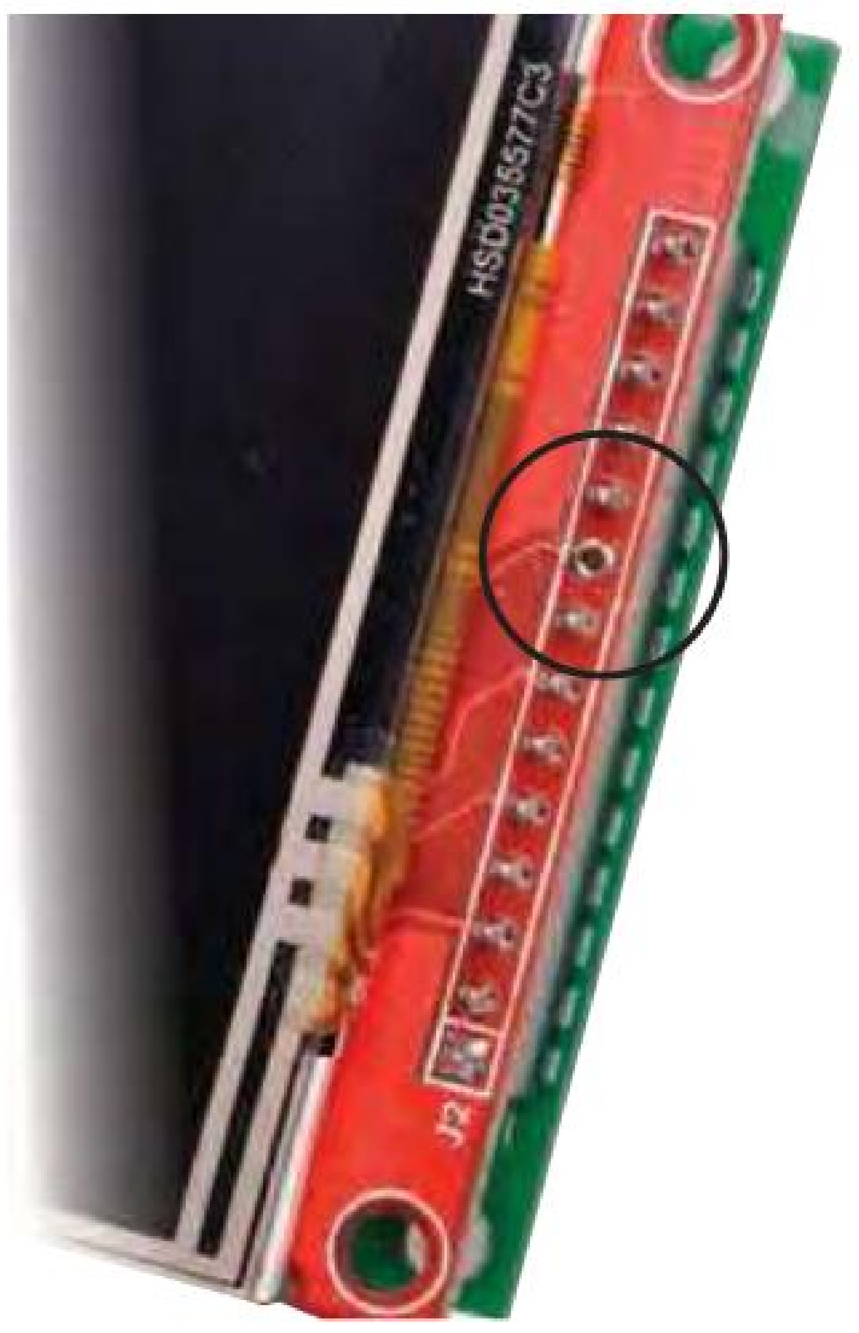
Type: All Topic: All Adafruit_GFX

Adafruit GFX Library by **Adafruit** Version **1.2.9** INSTALLED
Adafruit GFX graphics core library, this is the 'core' class that all our other graphics libraries derive from. Install this library in addition to the display library for your hardware.

Screen2: both the Adafruit_GFX and MCUFRIEND_kbv libraries can be installed through the Arduino IDE's Library Manager. Use the search terms above to help find them.



The serial 3.5-inch touchscreen: the reverse of the PCB is quite bare Except for an SD card socket and the touch controller IC and its associated components.



The circle highlights the pin we had to remove during testing to resolve a conflict on the SPI bus (also shown at left). You shouldn't have to do this on your board!

microSD card slot

Even though the SD card socket on this display appears to be wired directly to the Arduino's I/O pins (and thus, would be driving a 3.3V device from 5V outputs), we tried the **listfiles** sketch as above, but this time changing the initialisation line to read:

```
if (!SD.begin(10)) {
```

to suit the Uno's pin mapping. Surprisingly, it worked. We suspect that we have a tough microSD card and would be surprised if it lasts long being directly driven from 5V pins.

The SOIC-8 footprint on the board also appears to be directly connected to 5V I/O pins as well, with its pin 1 (which is $\overline{\text{CS}}$ on many flash ICs) connected to pin A5 on the Uno.

Verdict

As noted above, this unit looks very tidy when paired with an Uno board, but since it leaves virtually no I/O pins free, it's hard to think of a useful application for it.

And as also mentioned above, if you use the obvious solution of upgrading to an Arduino Mega board, you lose most of its speed advantage over a serial display, since you can no longer do direct port writes.

That the shield appears to connect to the microSD card slot and Flash chip pins at 5V is concerning, and we would not recommend using those interfaces on these modules.

Building the Arduino breakout board

We are very happy with the 3.5-inch SPI display panels (the first ones described above). We felt that a proper breakout board was necessary to make it easier to connect them to an Arduino, avoiding the need for messy jumper wires. The circuit for this board is shown in Fig.5.

There isn't much to it. It mainly just routes the signals between the Arduino and display, while converting the Arduino's 5V signal swing to 3.3V to suit the LCD screen, touch panel and SD card interfaces.

There are seven 470Ω/1kΩ resistive dividers to achieve this. These are for the MOSI and SCK connections on the shared SPI bus, three $\overline{\text{CS}}$ lines (one each for the LCD, touch controller and SD card) and two extra control lines on the LCD controller; DC (data/command) and RESET.

Note that we haven't put a divider on MISO since it is a 3.3V signal coming out of the touch controller (or SD card), which a 5V Arduino boards can accept as-is. Per the data sheet, the minimum voltage level that an ATmega328 micro running from 5V is guaranteed to read as high is 3.0V. The board also supplies logic power (3.3V) to the display, which is taken from the Arduino's 3.3V supply, and power for the backlight LED(s), which comes directly from the Arduino's 5V supply.

The touch controller's T_IRQ line is not connected, as we felt that this would eat too much into the already dwindling number of available I/O pins on the Arduino.

We have provided connection pads to all unused pins on the Arduino, so they can be connected by jumper leads if needed. In most applications, we find that it is not necessary.

The SPI communication lines for the display are routed to the 6-pin ICSP header on the Arduino board. Since the introduction of the so-called 'R3' Arduino board layout, this is the location which is guaranteed to be connected to the Arduino's hardware SPI pins, regardless of which digital I/O pins they map to (that differs between various Arduino boards).

For this reason, the breakout board can be used with just about any 5V Arduino R3 board, and we've tested it with a few, including the Leonardo, Mega and Uno.

If you're not sure that your board is R3 compatible, check that it has the ICSP header approximately halfway between the TX/RX pins and the analog pins. It should also have one 10-way, two 8-way and one 6-way female pin headers. Earlier versions typically lack the 10-way header.

As noted earlier, JP1 can be used to connect the MISO line to the LCD controller, but generally, you will want to leave this open, or else the touch controller interface may not work.

The PCB also has mounting holes for both the 2.8-inch and 3.5-inch display panels, as well as the Arduino board itself. The remaining spare room is occupied with a small prototyping area with 5V, 3.3V and GND connections nearby, and all unused Arduino pins have adjacent breakout pads.

There's also a slot which allows the end of the PCB to be broken off if you are using it for the 2.8-inch display, as otherwise the board is 13mm wider than it needs to be.

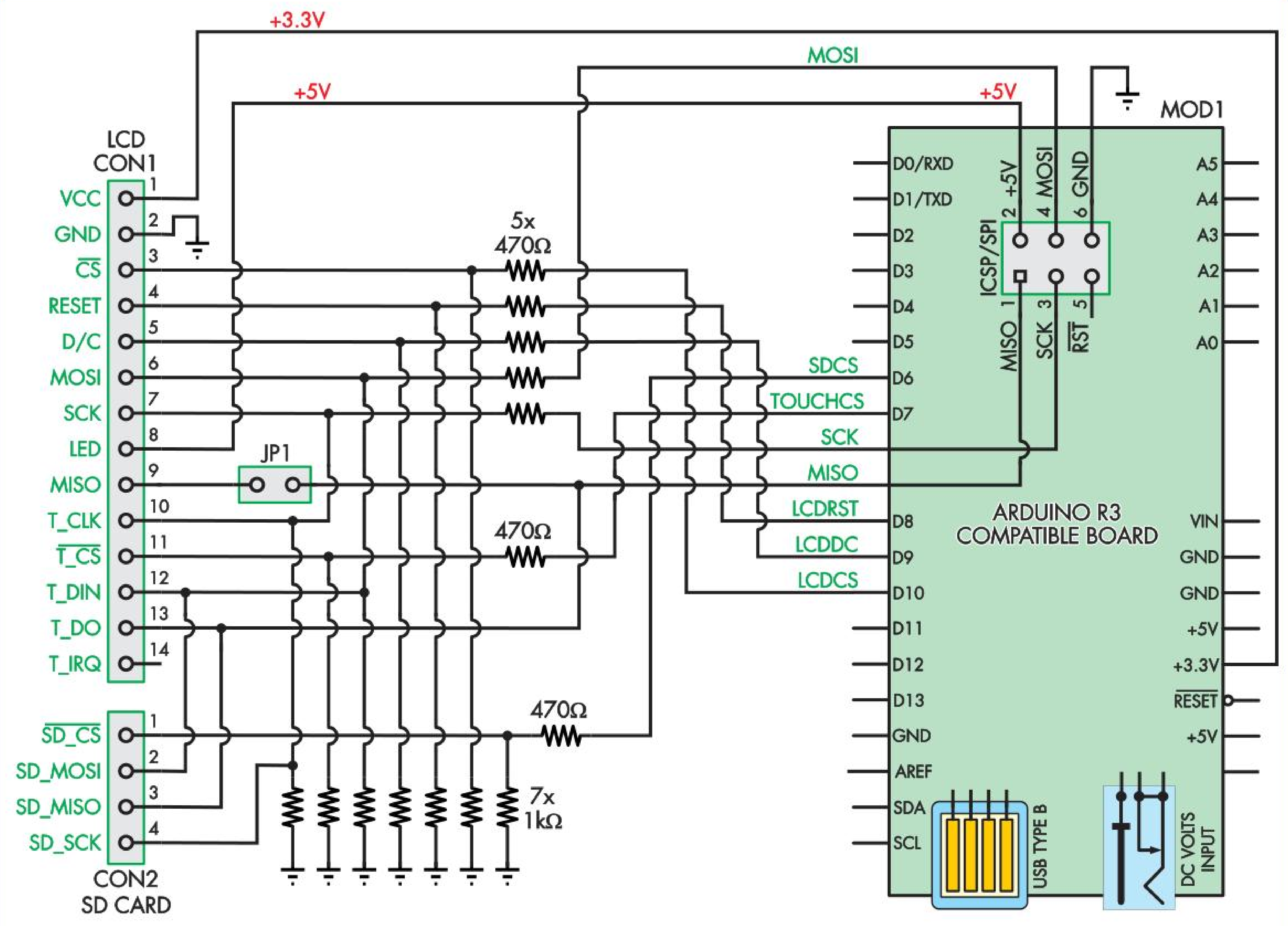
Construction

The breakout board PCB is coded 24111181 and measures 98 × 55mm. Use Fig.5, the PCB overlay diagram, during assembly.

Parts list – Arduino breakout board

1 double-sided PCB coded 24111181, 98x55mm
1 3.5-inch 480x320 pixel ILI9488-based LCD touchscreen with SPI interface
1 Arduino R3-compatible board, such as the Uno R3, Mega R3 or Leonardo R3
1 10-way pin header
2 8-way pin headers
1 6-way pin header
1 4-way pin header
1 14-way female header (CON1)
1 4-way female header (CON2)
2 3-way female header strip ***OR***
3 2-way female header strips
4 12mm-long M3 tapped spacers
8 6mm M3 panhead machine screws
1 2-way male header strip and jumper shunt (JP1; optional)

Resistors (all 1/4W 1% or 5%)
7 1kΩ   7 470Ω


+3.3V
MOSI
+5V
+5V
MOD1
LCD
CON1
VCC
GND
CS
RESET
D/C
MOSI
SCK
LED
MISO
T_CLK
T_CS
T_DIN
T_DO
T_IRQ
1
2
3
4
5
6
7
8
9
10
11
12
13
14
JP1
5x
470Ω
470Ω
470Ω
7x
1kΩ
SD_CS
SD_MOSI
SD_MISO
SD_SCK
1
2
3
4
CON2
SD CARD
SDCS
TOUCHCS
SCK
MISO
LCDRST
LCDDC
LCDCS
D0/RXD
D1/TXD
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
GND
AREF
SDA
SCL
ICSP/SPI
2 +5V
4 MOSI
6 GND
MISO 1
SCK 3
RST 5
A5
A4
A3
A2
A1
A0
ARDUINO R3
COMPATIBLE BOARD
VIN
GND
GND
+5V
+3.3V
RESET
+5V
USB TYPE B
DC VOLTS
INPUT

3.5-inch Touchscreen Arduino Adaptor

Fig.5: the breakout board circuit routes the connections between the Arduino pins and LCD touchscreen headers, while providing level translation to allow the 5V Arduino to drive the 3.3V chips on the LCD board. This conversion is done using 1kΩ/470Ω resistive dividers.

If you wish to cut down your board to suit a 2.8-inch display, this should be done first, to avoid damage to installed components. Run a sharp knife over the four tracks crossing the narrow bridge to cut them cleanly. This avoids any risk of them tearing and lifting off the board.

Now use broad-edged pliers to gently flex the board along the line of the slot until it breaks. You may like to clean up the rough edges with a file; we recommend doing this outside, preferably with a face mask to avoid inhaling fibreglass dust.

The resistors are the first parts to fit, where shown in Fig.6. The 1kΩ resistors will have colour bands of either brown-black-red-gold or brown-black-black-brown-brown, while the 470Ω resistors will have either yellow-violet-brown-gold or yellow-violet-black-black-brown.

You can leave the header for JP1 off (you probably won't need it) but if you do want to install it, do so now. You can mount the header but leave the shunt off at first if you aren't sure.

Next, fit the five headers which connect to the Arduino board. The easiest and neatest way to do this is to use the Arduino board itself as a jig.

Plug the 6-way, 8-way, 10-way male headers and the 2×3-way female header into the Arduino board and then slot the breakout board on top. Ensure it is flush and pushed down firmly before soldering the headers into place. All these header pins are soldered from the top side of the board.

Check the headers are correctly soldered, and unplug the breakout board from the Arduino board.

Use a similar technique for the headers that connect to the display panel, although you may find that your display panel does not come with the 4-pin male header fitted.

Assuming this is the case, plug the 4-way male header into the 4-way female header, then plug the 14-way female header onto the display panel's pin header.

Put the 4-way male header end into the display panel and rest the breakout board on top, ensuring that all 18 header pins are in their correct locations.

Now solder the headers onto the breakout board and then flip the assembly over to solder the 4-way male header to the display panel. The breakout board is now complete and can be plugged back into the Arduino.

Optionally, you can use tapped spacers and machine screws to secure the display panel to the breakout board. Mount the spacers to the display panel with the spacers behind and the screws on top. Fit the breakout board to the rear of the display panel, and secure with the four remaining screws. There will be a slight gap between the male and female headers as the 12mm spacers are longer than the approximately 11mm combined height of the headers, but they should still make good contact so this shouldn't cause any problems.

Software

The sketches we have created are designed to stand on their own and do not require any separate libraries to be installed. The ZIP download package contains three sample sketches, all starting with 'SPI'.

Extract the contents of the .zip file to somewhere on your computer, and open one of the files with the Arduino IDE. Select the appropriate board and port combination, and click 'Upload'. The three examples work as follows:

1) **SPI_320x480_display_demo** draws boxes, lines and text to the display as it cycles through the four possible orientation settings (two in portrait and two in landscape).
2) **SPI_3.5_inch_TFT_shield_demo_wth_touch** shows off the touch feature by drawing lines and displaying the current touch coordinates to the display.

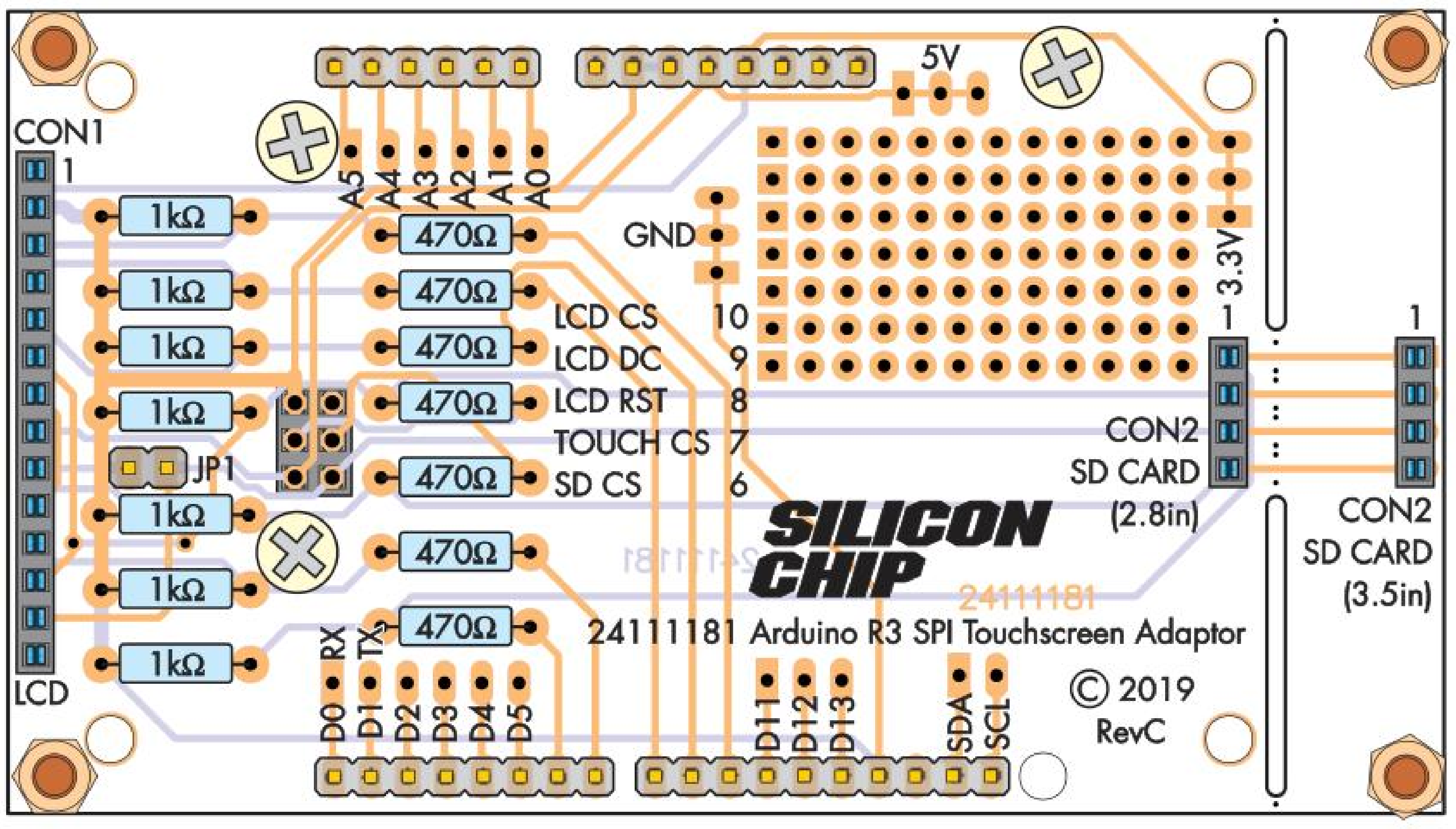
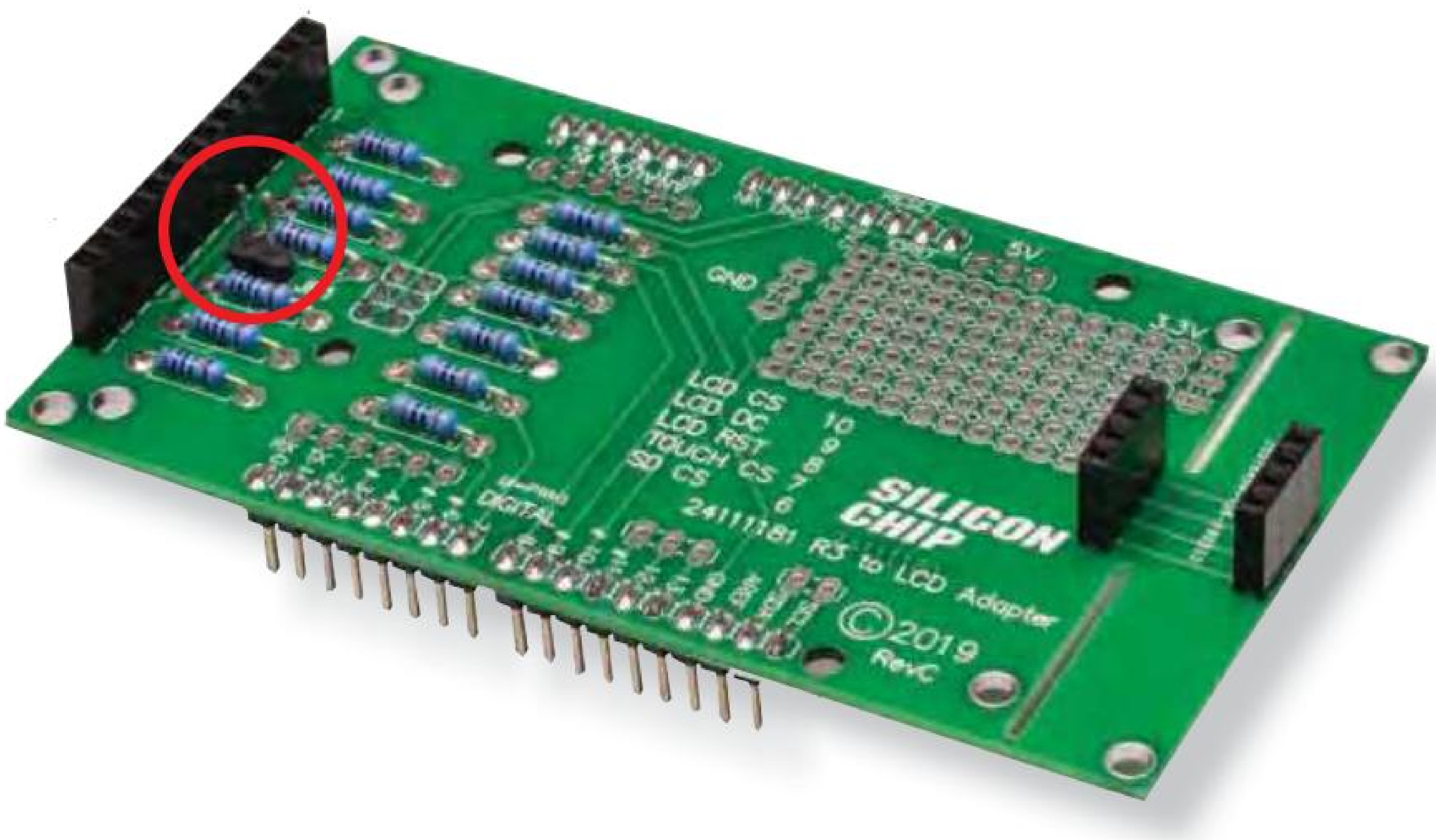

CON1
1
LCD
1kΩ
1kΩ
1kΩ
1kΩ
1kΩ
1kΩ
1kΩ
JP1
A5
A4
A3
A2
A1
A0
470Ω
470Ω
470Ω
470Ω
470Ω
470Ω
470Ω
GND
LCD CS 10
LCD DC 9
LCD RST 8
TOUCH CS 7
SD CS 6
5V
3.3V
1
1
CON2
SD CARD
(2.8in)
CON2
SD CARD
(3.5in)
SILICON CHIP
24111181
24111181 Arduino R3 SPI Touchscreen Adaptor
© 2019
RevC
RX
TX
D0
D1
D2
D3
D4
D5
D11
D12
D13
SDA
SCL

Fig.6: use this PCB overlay diagram as a guide when building the breakout board. After fitting the resistors where shown, you just need to solder the headers in place. Some go on the top while those which plug into the Arduino are mounted on the bottom.



The completed R3 to LCD Adaptor. Note the jumper (highlighted above) is not populated and we have fitted headers for both 3.5 and 2.8-inch displays, although you will probably only use one (fit one or the other). If using the 2.8-inch display, you can break this PCB along the slots at the right side.

3) **SPI_3.5_inch_TFT_touch_calibration** can be used to fine-tune the touch settings, although we found the default calibration worked fine with three different screens.

The touch calibration sketch requires the Arduino Serial Monitor to be running. During the calibration stage, it will send four lines of text to the Monitor that should be copied over the similar lines in any sketch that uses these touch routines. For example:

```
#define TOUCH_X0 1
#define TOUCH_X1 2001
#define TOUCH_Y0 199
#define TOUCH_Y1 76
```

You might also like to experiment with the library we mentioned earlier, remembering to change the pin definitions near the start of the **graphicstest** sketch like this:

```
#define TFT_CS     10
#define TFT_DC     9
#define TFT_LED    -1
#define TFT_RST    8
```

The library can also be installed via the Library Manager by searching for **ili9488** (see Fig.4). It also requires the **Adafruit_GFX** library to be installed, which can be found by searching for its name in the Library Manager.

In the software resource bundle for this project, we've included .zip files of the current versions of these open-source libraries in case you have trouble finding them.

Future updates

Now that we have confirmed that these displays can be used on both the Arduino and Micromite platforms, we plan to use them in future projects.

To enable IL9488-based displays to work with a Micromite at an acceptable display update speed, please do read the panel below.

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Update from The Back Shed

While we were preparing this article, Geoff Graham told us that Peter Mather had made a post on his forum, 'The Back Shed', describing a driver that he had created for the ILI9488 display controller.

The Back Shed is a great place to get information on the various Micromites and other topics. See: **www.thebackshed.com/forum/**

His code for the display controller can be found at the Back Shed: **https://bit.ly/pe-jun20-bkshd-11419**

It is implemented as a CSUB which is run by the Micromite at startup. This is a different initialisation process than you would use with one of the natively support displays, but after that, you use the usual native graphics commands.

The code shown on the forum is for a different Micromite board, so the initialisation line needs to be changed to suit the pinouts used on the BackPack. Copy and paste his code labelled 'MM2' into a blank program, then change the second line from:

```
ILI9488 16,2,9,1
```

to:

```
ILI9488 2,23,6,1
```

These parameters determine the display CD pin, RST pin, $\overline{\text{CS}}$ pin and orientation. This changes the pin values to suit the BackPack. The orientation is a value from 1 to 4, as explained in the main text of this article. Upload the program to the Micromite and run the command:

```
LIBRARY SAVE
```

to store the CSUB as a library instead of BASIC code, then restart the processor with the command:

```
WATCHDOG 1
```

The driver will then be loaded. At this stage, the Micromite is at the same state as if the OPTION LCDPANEL command had been run for the 2.8in screen, and normal touch panel initialisation can continue, like this:

```
GUI TEST LCDPANEL
OPTION TOUCH 7,15
GUI CALIBRATE
GUI TEST TOUCH
```

Since this approach is so much faster, uses less Flash and lets you use the normal built-in graphics commands, we think most Micromite users will prefer this approach. The only disadvantage is that you lose the ability to use the SPI peripheral for other purposes, as is the case with the usual 2.8-inch display.

Micromite BackPack notes

Peter also noted the glitch with the MISO pin on these displays which we found (and worked around) while while trying them out in this article and then on the future V3 BackPack board, which will be launched on *Practical Electronics* in a few month's time.

Finally, future releases of the Micromite V2 firmware will include a copy of Peter Mather's ILI9488 CSUB driver.

Win a Microchip PIC-IoT WA Development Board

Practical Electronics is offering its readers the chance to win a Microchip PIC-IoT WA Development Board (EV54Y39A) – *and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these boards.*

The PIC-IoT WA Development Board combines a powerful PIC24FJ128GA705 MCU, an ATECC608A CryptoAuthentication secure element IC and the fully certified ATWINC1510 Wi-Fi network controller, which provides the most simple and effective way to connect your embedded application to Amazon Web Services (AWS). The board also includes an on-board debugger and requires no external hardware to program and debug the MCU.

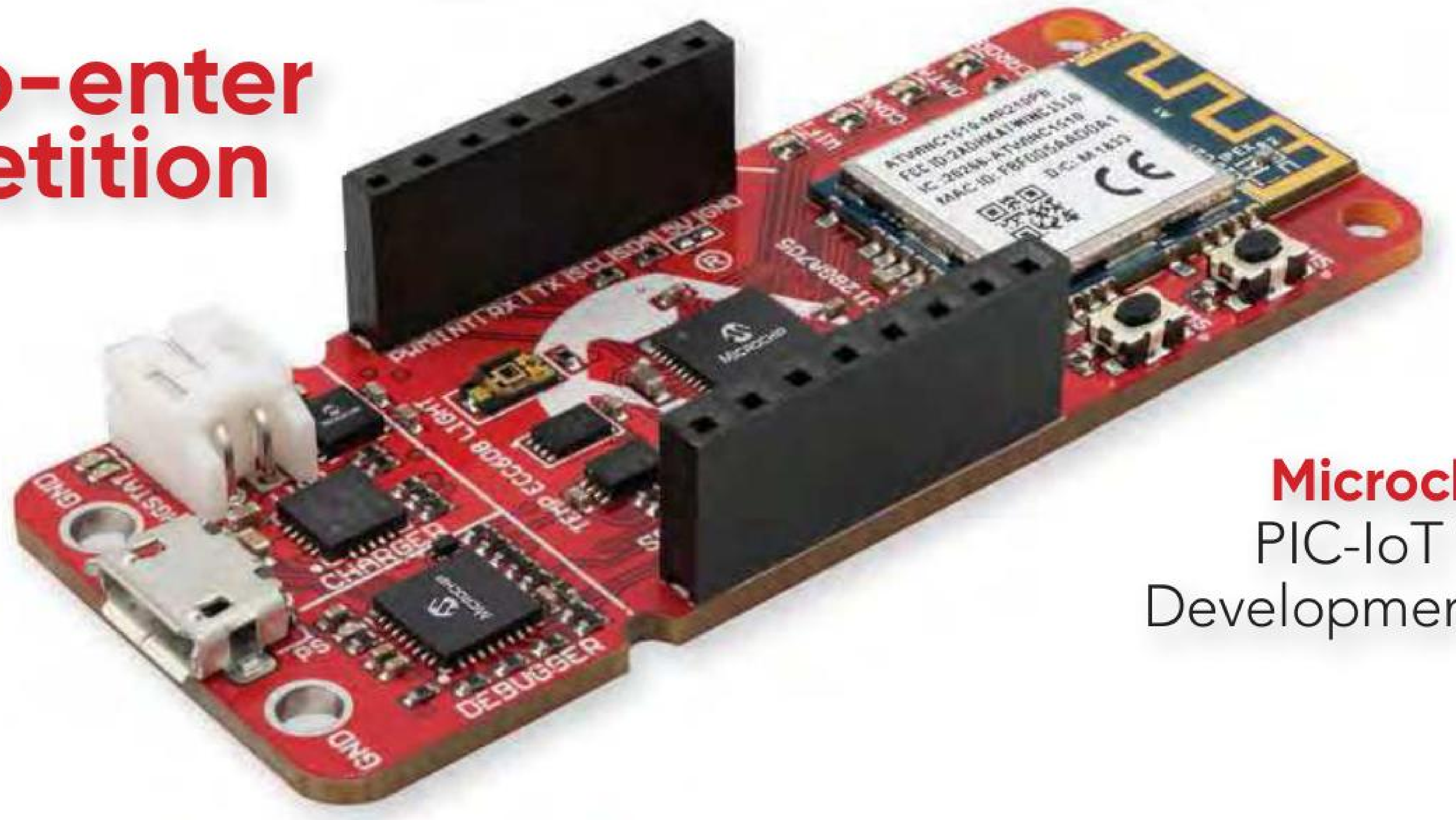
Out of the box, the MCU comes preloaded with firmware that enables you to quickly connect and send data to the AWS platform using the on-board temperature and light sensors. Once you are ready to build your own custom design, you can easily generate code using the free software libraries in MPLAB Code Configurator (MCC).

The PIC-IoT WA Board is supported by MPLAB X IDE and features the following elements:

- Supports many PIC microcontrollers and dsPIC DSCs
- The on-board debugger (PKOB nano) supplies full programming and debugging support through MPLAB X IDE. It also provides access to a serial port interface (serial to USB bridge) and one logic analyser channel (debug GPIO).
- The on-board debugger enumerates on the PC as a mass-storage interface device for easy 'drag and drop' programming, Wi-Fi configuration, and full access to the microcontroller application Command Line Interface (CLI).
- A mikroBUS socket allows for the ability to expand the board capabilities with the selection from 450+ sensors and actuators options.
- A light sensor used to demonstrate published data.
- Microchip MCP9808 high-accuracy temperature sensor used to demonstrate published data and MCP73871 Li-Ion/LiPo battery charger with power path management.

Worth $29.00 (approx £23.50) each

Free-to-enter competition



Microchip
PIC-IoT WA Development Board

How to enter

For your chance to win a Microchip PIC-IoT WA Development Board or receive a 20% off voucher, including free shipping, enter your details in the online entry form at:

https://page.microchip.com/PE-PIC-IoT.html

Closing date

The closing date for this offer is 30 May 2020.

February 2020 winner

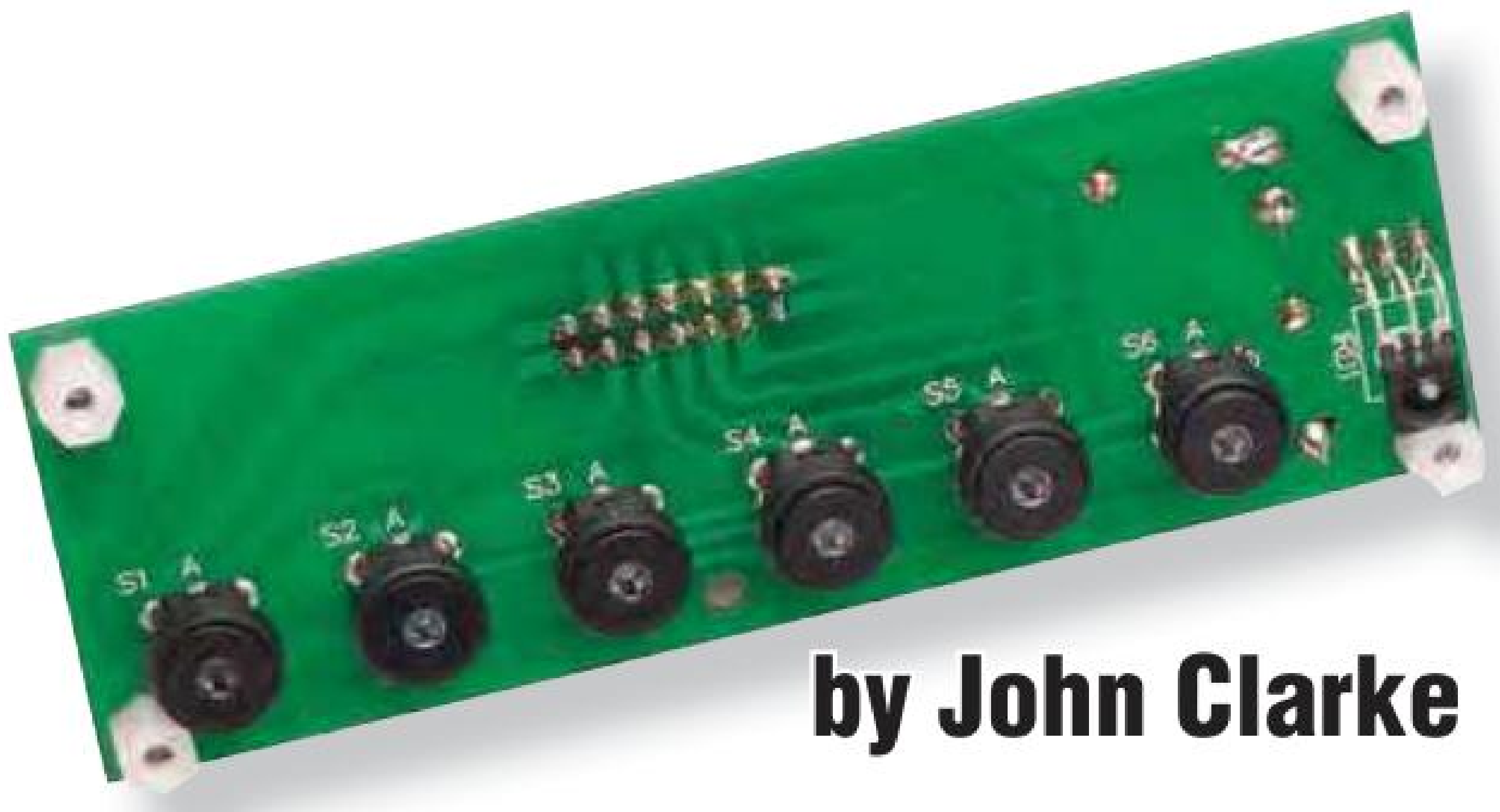
Edouard Pedro

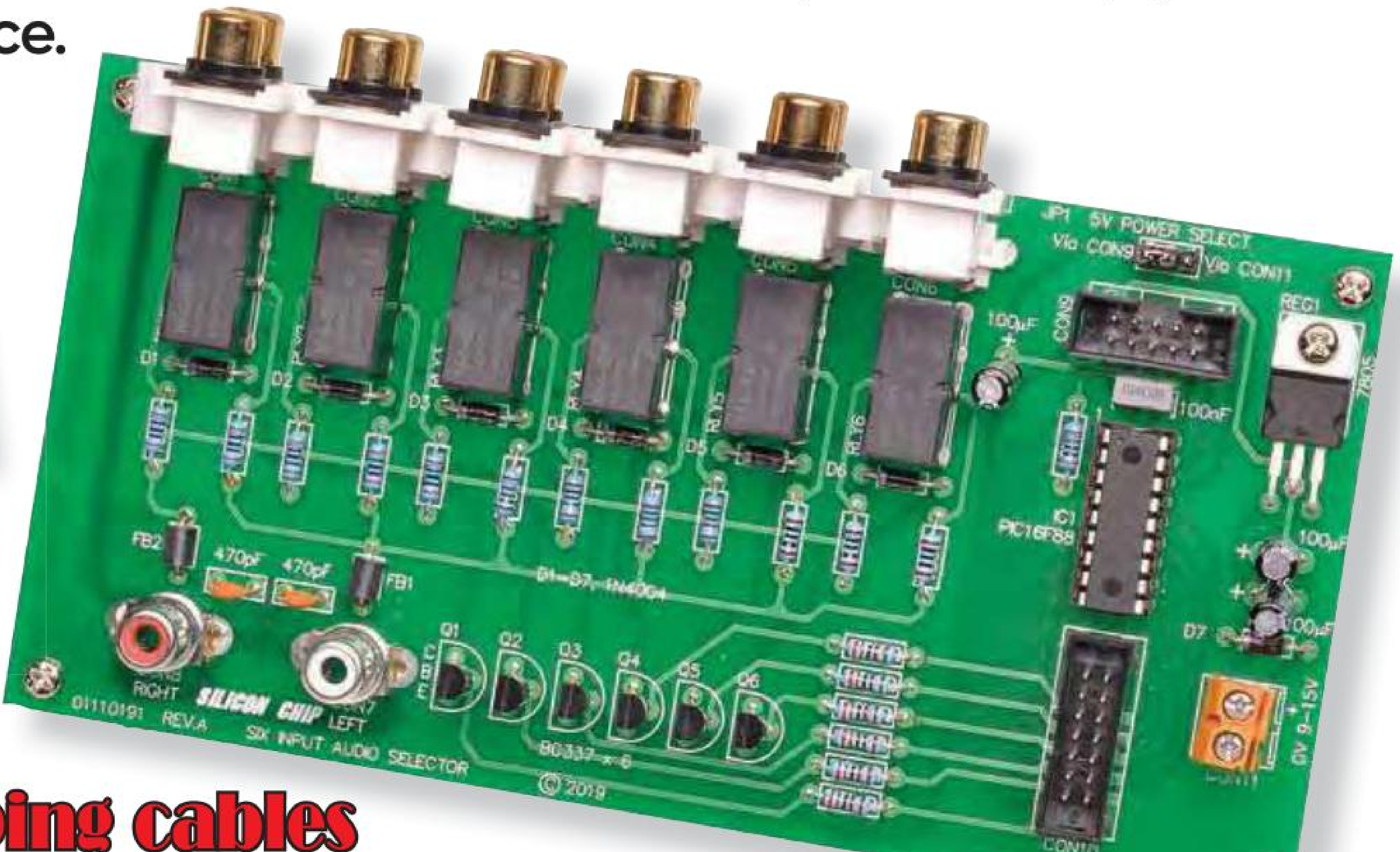
He won a Microchip MCP3564 ADC Evaluation Board for PIC32 MCUs

Ultra-low-distortion Preamplifier with Tone Controls

Part 3

This high-performance Audio Selector can expand the number of inputs to the Ultra-low-distortion Preamplifier. It can also be used to 'upgrade' just about any piece of audio equipment with stereo line level inputs or simply operate as a stand-alone device. Here we discuss both options.





by John Clarke

Six-input Stereo Audio Selector – no more swapping cables every time you want to change audio sources!

If you're one of those people who enjoys listening to music from a variety of sources, you'll know just how much of a pain unplugging and replugging cables can be.

For example, you might want to listen to CDs or DVDs one day, an MP3 player another, and a turntable on another. Other times there's the audio from your TV... but most of the time it's a DAB, FM or AM tuner. That's five but there are many more.

Our current *Preamplifier* project was designed to switch between three stereo sources, using either a remote control or front panel pushbuttons. And while three inputs are enough for many people, inevitably, some need more!

This *Preamplifier* is a very high-performance stereo unit, with vanishingly low noise and distortion. It has remote-controlled volume and input switching, with stereo and bass tone controls.

While it is possible to add an external input switcher to expand the number of available inputs (eg, our January 2013 *Three Input Switcher*), that's an unsatisfying solution. After all, who wants an extra box and an extra remote control?

This project expands the number of stereo inputs to the *Preamplifier* (or indeed any other preamp or all-in-one) to six, which should satisfy most people. Yes, we know that there will be people who need seven or eight, but you have to stop somewhere!

It's an easy upgrade. Simply build the two new boards, wire them up to the existing *Preamplifier* main board and reprogram the *Preamplifier's* microcontroller and you'll have more inputs! You can still use the same remote control to adjust the volume and switch between the six input pairs.

So that you can use it with other preamp designs, or other equipment entirely, we have designed it so that it can be used as a standalone unit. All you need to do is build the boards, put them in a box and connect a small 9-15V DC power supply and you have a remote-controlled *Six-input Selector* with front panel pushbuttons and LED indicators.

You can control it with just about any universal remote.

Overall design

The *Audio Selector* consists of two PCBs. The main one has the six stereo inputs, one pair of stereo output sockets and the relays used for switching between the inputs.

The control PCB has the six pushbutton switches to select each input, with integral LEDs and mounts on the front panel of the unit.

The two PCBs are connected by a 14-way ribbon cable with IDC connectors at each end. When used as a standalone unit without the *Preamplifier*, an infrared receiver can be included on the control PCB. The main PCB also has a 5V regulator to power the whole circuit from a 9-15V DC source.

When used with the *Preamplifier*, the *Audio Selector* is connected to the main *Preamplifier* board via a 10-way ribbon cable with IDC connectors. In this case, the *Audio Selector* is powered from the *Preamplifier* over this cable. The infrared receiver on the *Preamplifier* is then used to control the *Audio Selector* as well as adjusting the volume on the *Preamplifier*.

This requires revised firmware to be loaded onto the *Preamplifier* microcontroller. If you have a PIC programmer, you can download the software from the June 2020 page of the *PE* website and reprogram the chip yourself.

If you are buying your *Preamplifier* parts as a kit from Altronics (code K5171) then the microcontroller will be supplied ready for the *Six-input Audio Selecctor* – no reprogramming needed.

Circuit description

Fig.17 shows the circuit of the main (switching) board, while Fig.18 is the circuit diagram of the front panel control board.

Let's start with the main circuit, Fig.17. It's based around microcontroller IC1, which drives the DPDT input selection relays (RLY1-RLY6) via NPN transistors Q1-Q6 and monitors the switches and infrared receiver via CON10.

When the circuit is powered up, the coil of one of six relays RLY1-RLY6 is energised at any given time. Each relay's pair of COM terminals is connected to its corresponding pair of RCA input sockets, CON1-CON6. So when its coil is energised, those signals are fed through a pair of 100Ω series resistors and ferrite beads FB1 and FB2 to the output sockets, CON7 and CON8.

The series resistors, ferrite bead and 470pF capacitors heavily attenuate any ultrasonic signals which may be picked up by the *Preamplifier* inputs and wiring. Such signals often come from electromagnetic emissions from nearby equipment or broadcast radio stations (the wires act like antennas). However, we only want to feed audio (20Hz-20kHz) signals to the following equipment.

One end of each relay coil is permanently connected to the +5V supply, while the other end is connected to ground by one of six NPN transistors, Q1-Q6. Each of these transistors has a 2.2kΩ base-current limiting resistor, which is driven by one of the digital outputs of IC1; RA2 (pin 1) for Q1, RA3 (pin 2) for Q2 etc.

So when one of these outputs goes high, the base-emitter junction of the corresponding transistor is forward biased, switching on that transistor and pulling current through the connected relay coil, energising it.

When that output goes low, the transistor switches off and the connected diode (one of D1-D6) prevents the coil from generating a high-voltage spike as its magnetic field collapses, which could damage the connected transistor.

When used as a standalone unit, an external source of DC power is applied to terminal block CON11, and this is regulated to 5V by REG1 to power the relays and IC1. Diode D7 provides reverse polarity protection while 100µF capacitors are used for input bypassing and output filtering of REG1. JP1 is fitted in the upper position.

When used as part of a *Preamplifier*, 5V power comes from pins 7 and 8 of CON9, with the ground connection made at pins 9 and 10. In this case, JP1 is fitted in the lower position. IC1 has a 100nF bypass capacitor and 10kΩ reset pull-up resistor to ensure correct operation.

Control board circuitry

As shown, CON10 on the main board connects to CON12 on the control board (Fig.18). This allows microcontroller IC1 to detect when one of the front panel pushbuttons is pressed and also illuminate the LED in one of the buttons, to indicate the currently selected input.

LED1-LED6 are housed within pushbuttons S1-S6. Their cathodes are joined together and to a 2.2kΩ resistor to ground, setting the maximum LED current to around 0.8mA ([5V – 3.3V] ÷ 2.2kΩ). One LED anode is driven to +5V to light it up and the others are left low at 0V, turning off the other LEDs.

This is done via pins 5, 7, 9, 11, 13 and 14 of CON12, which connect back to the same pins on IC1 as are used to drive the relays via the six transistors (see Fig.17).

Hence, whenever a relay is activated by that output going high, the corresponding LED on the front panel lights up.

The pushbutton switches are connected in a 'matrix' manner to pins 3, 4, 6, 8 and 10 of CON12. This reduces the number of pins needed to sense a press of one of the six buttons by one (to five). Pins 3 and 4 of CON12/CON10 connect to the RB3 and RB4 outputs of IC1, while pins 6, 8 and 10 of these connectors go to the RB5, RB6 and RB7 inputs of IC1. These inputs are typically held at 5V via pull-up currents which are internal to IC1.

Switches S1, S3 and S5 have one side connected to the RB4 output, while switches S2, S4 and S6 have one side connected to the RB3 output. The other sides of the switches are monitored by the RB5, RB6 and RB7 inputs.

Periodically, outputs RB3 and RB4 are briefly brought low in turn, and if one of the three inputs (RB5, RB6 or RB7) goes low at the same time, that means one of the three switches connected to that output has been pressed.

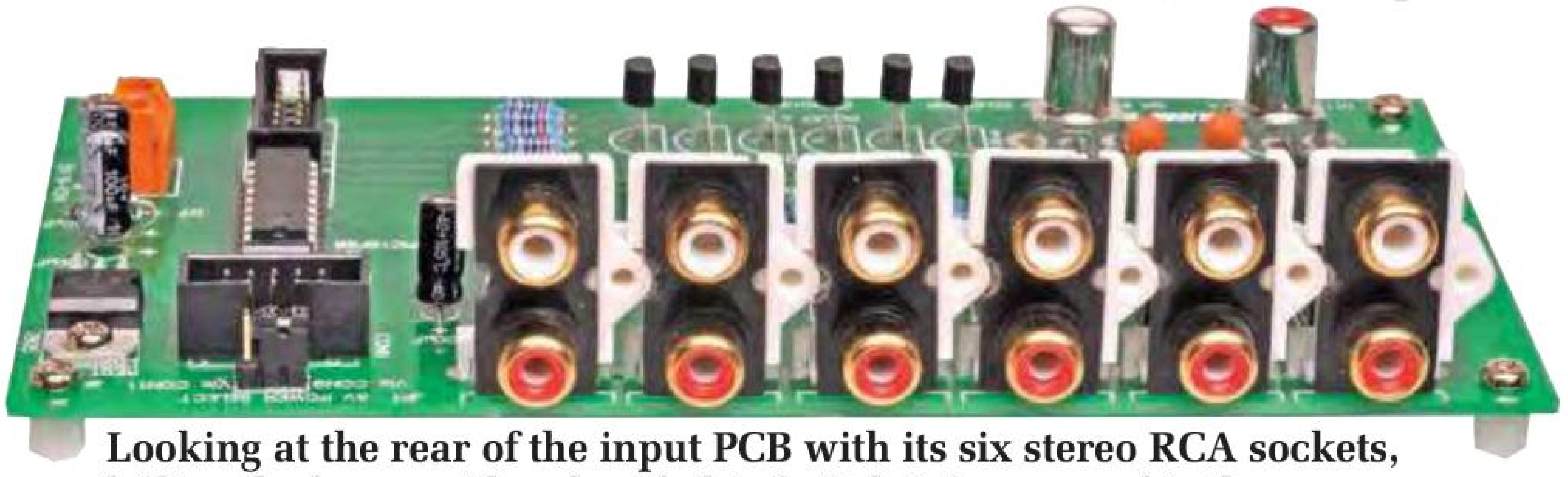
The micro figures out which one has been pressed based on which combination of these five pins is low and switches to the selected input.

The current input can also be changed by infrared remote control. Infrared receiver IRD1 is a complete infrared detector and processor; its 5V supply is filtered by a 100Ω resistor and 100µF capacitor. It receives the 38kHz signal from the remote control, amplifies, filters and demodulates it. The result is a serial data burst at its pin 1 output. This is fed

Features

- Six stereo inputs
- Input selection via pushbutton or infrared remote control
- LED indicators to show currently selected channel
- Remembers currently selected input even when powered off
- Build as a standalone unit or incorporated into one of two high-performance preamplifiers
- No mains wiring required; can run off low-voltage DC
- Retrofit to suitable existing preamplifiers
- Negligible noise and distortion
- Easy construction
- Uses common parts

Constructors – please see note in the April 2020 issue Parts List before purchasing components.



Looking at the rear of the input PCB with its six stereo RCA sockets, hiding the low-profile relays behind. At left foreground is the connector which has the cable connecting to the *Preamplifier* board.

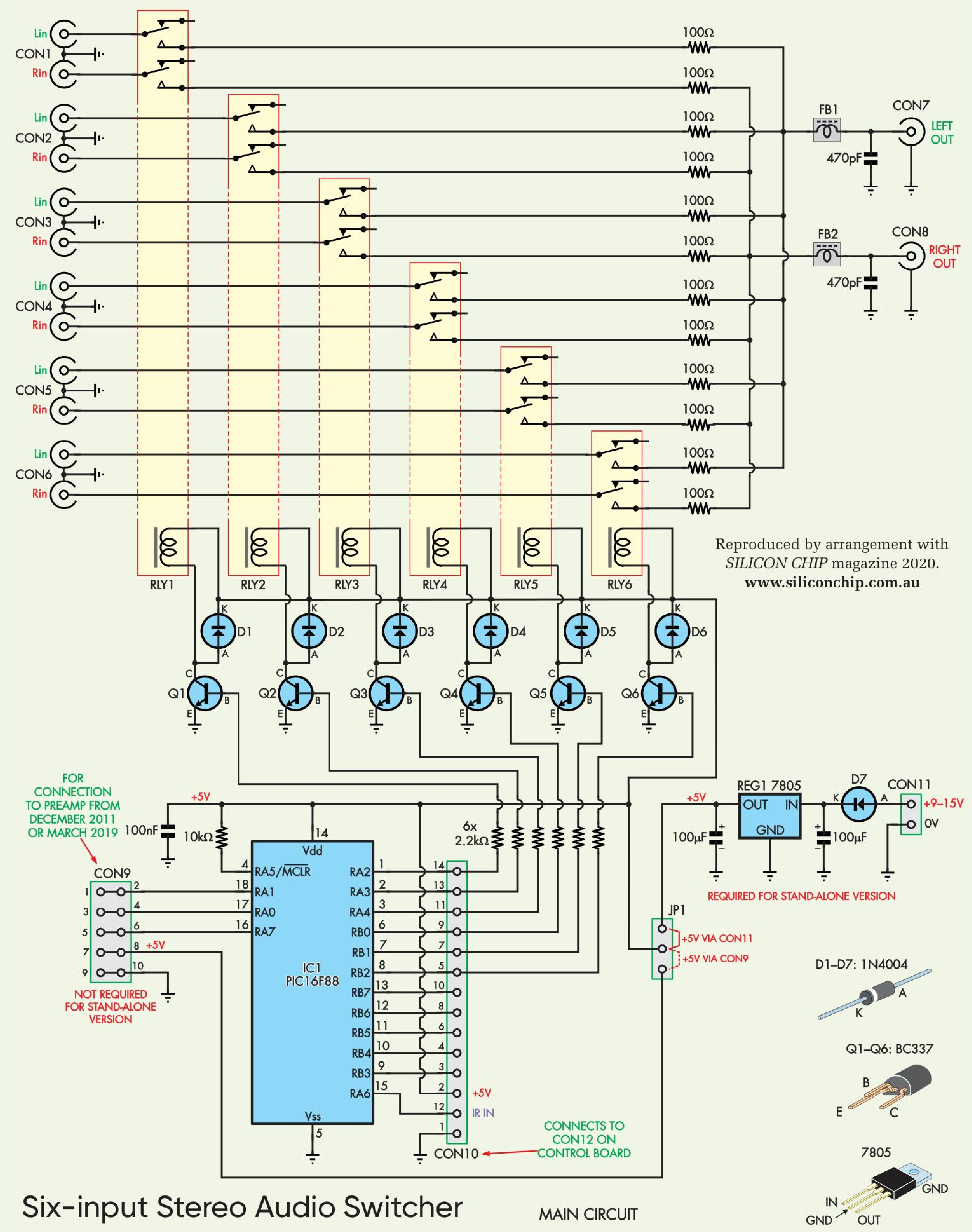

Lin
CON1
Rin
Lin
CON2
Rin
Lin
CON3
Rin
Lin
CON4
Rin
Lin
CON5
Rin
Lin
CON6
Rin
100Ω
FB1
CON7
LEFT OUT
470pF
FB2
CON8
RIGHT OUT
470pF
RLY1
RLY2
RLY3
RLY4
RLY5
RLY6
K
A
D1
D2
D3
D4
D5
D6
C
B
E
Q1
Q2
Q3
Q4
Q5
Q6
FOR CONNECTION TO PREAMP FROM DECEMBER 2011 OR MARCH 2019
CON9
NOT REQUIRED FOR STAND-ALONE VERSION
+5V
100nF
10kΩ
14
Vdd
6x 2.2kΩ
RA5/MCLR
RA1
RA0
RA7
RA2
RA3
RA4
RB0
RB1
RB2
RB7
RB6
RB5
RB4
RB3
RA6
IC1 PIC16F88
Vss
5
CON10
+5V
IR IN
CONNECTS TO CON12 ON CONTROL BOARD
REG1 7805
OUT
IN
GND
D7
CON11
+9–15V
0V
100µF
REQUIRED FOR STAND-ALONE VERSION
JP1
+5V VIA CON11
+5V VIA CON9
D1–D7: 1N4004
Q1–Q6: BC337
7805
IN
GND
OUT
Six-input Stereo Audio Switcher
MAIN CIRCUIT

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Fig.17: the circuit of the main *Audio Selector* board. Microcontroller IC1 switches on one of the six relays, to connect the appropriate pair of input sockets to the output, using NPN transistors Q1-Q6. It connects to the front panel pushbutton/LED board via CON10. That front panel board also hosts the infrared receiver, if built as a standalone unit. If part of a *Preamplifier*, the IR receiver is on the *Preamplifier* board, which is connected via CON9.

to the RA6 digital input of IC1via pin 12 of CON12.

Software within IC1 determines whether the received code is valid and if so, which button on the remote control has been pressed and whether that corresponds to one of the six inputs. If it does, it switches to the new input.

Regardless of which method is used to select an input, as well as changing over the relays as needed, IC1 stores the current input selection in its permanent EEPROM memory so that the same input will be selected the next time the unit is powered up.

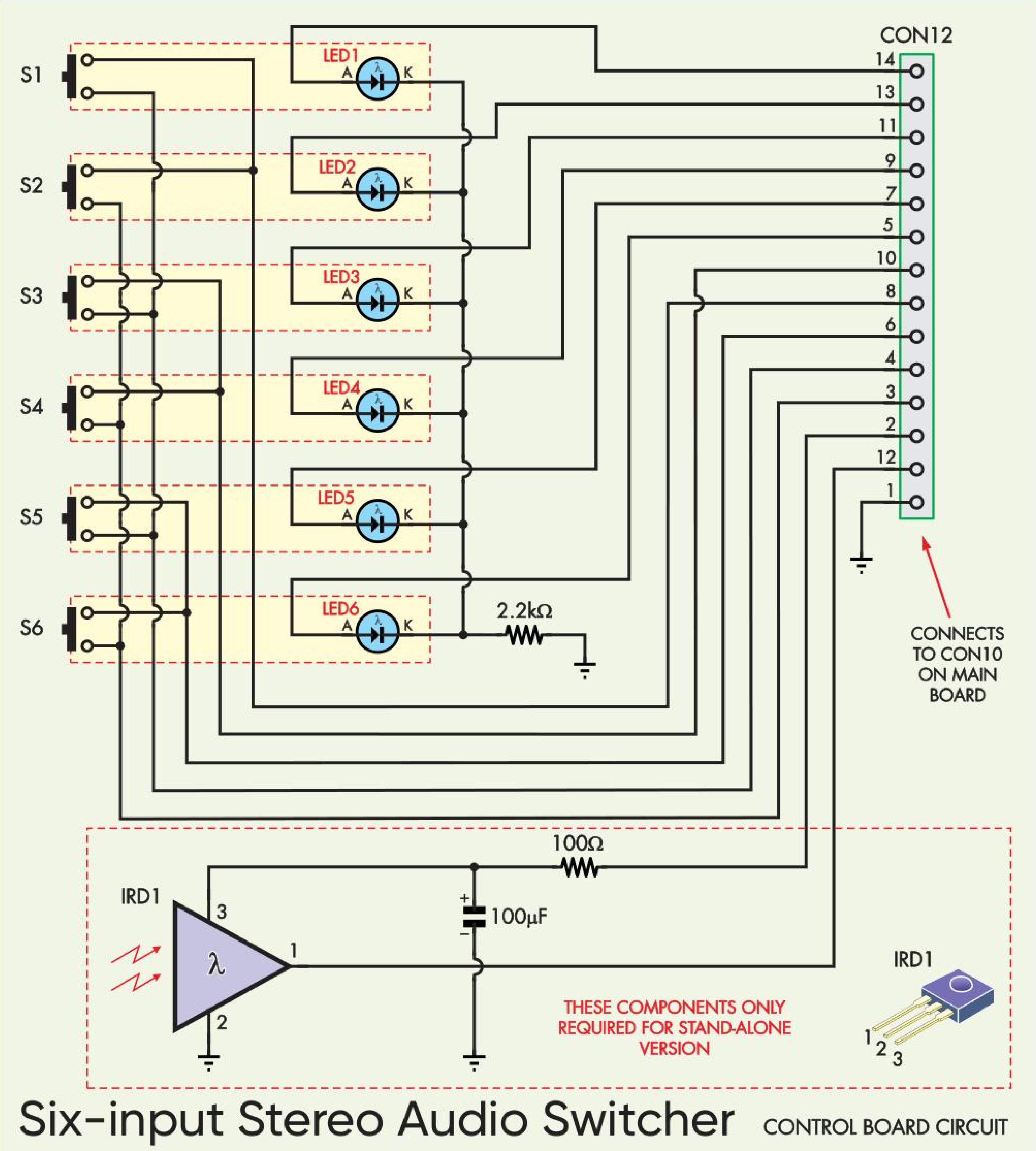

S1
S2
S3
S4
S5
S6
LED1
LED2
LED3
LED4
LED5
LED6
A
K
CON12
14
13
11
9
7
5
10
8
6
4
3
2
12
1
2.2kΩ
CONNECTS TO CON10 ON MAIN BOARD
100Ω
IRD1
3
λ
1
2
+
100µF
THESE COMPONENTS ONLY REQUIRED FOR STAND-ALONE VERSION
IRD1
1
2
3
Six-input Stereo Audio Switcher
CONTROL BOARD CIRCUIT

Fig.18: the circuit of the front panel control board is quite simple; it mainly hosts pushbuttons S1-S6, which have integral LEDs, plus the infrared receiver and its supply filter, which are only fitted if building the *Audio Selector* as a standalone unit. Otherwise, these parts will already exist on the *Preamplifier* board.

If the *Audio Selector* circuit is built as part of the *Preamplifier*, IRD1 and its supply filter components are not fitted. The infrared receiver on the preamplifier board is used instead. This controls the volume on the *Preamplifier* directly. If an input change is required, the *Preamplifier* board sends a coded signal over pins 1-6 of CON9.

These signals are fed to the RA1, RA0 and RA7 inputs of IC1 (pins 18, 17 and 16). The signals carry serial data indicating which input has been selected.

If you built the *3-input Preamplifier* and you are now upgrading to the *6-input* version, the microcontroller on the *Preamplifier* must be reprogrammed to send these signals, as the earlier designs did not have this capability. (The revised firmware, coded 0111111M.HEX, can be downloaded from the June 2020 page of the *PE* website.) Once IC1 receives valid serial data from that micro, it switches inputs as required.

Construction

The components for the circuit shown in Fig.17 are fitted to a double-sided PCB coded 01110191, and measuring 165 × 85mm. The separate control section components are mounted on a double-sided PCB, coded 01110192, and measuring 106 × 36mm. Both boards are available from the *PE PCB Service*.The overlay diagrams for these boards, which indicate where the components go, are shown in Fig.19 and Fig.20. Start by building the main board.

Fit the resistors first, and be sure to check values with a DMM set to measure resistance.

Follow with diodes D1 to D6, and install D7 if building the standalone unit. Ensure that their cathode stripes face as shown, then feed resistor lead off-cuts through the ferrite beads and solder them in place.

We recommend that IC1 is installed using a socket. Make sure its pin 1 dot/notch faces toward CON9, as shown. Fit the two 470pF MKT/MKP/ceramic capacitors next. Any of these types can be used, but if you use ceramics, they must use the NP0 or COG dielectrics for excellent low-distortion performance.

If building the standalone version, you can now bend REG1's leads to fit the pads, attach it to the board using the specified machine screw and nut and solder and trim its three leads.

Mount the remaining capacitors such as the 100nF MKT polyester or ceramic and the 100µF electrolytic capacitors. Electrolytic capacitors are polarised so the longer positive leads must go through the holes marked '+'. Note that only one 100µF capacitor is needed when the Audio Selector is used as part of a *Preamplifier*.

Fit the six transistors next. You may need to gently bend their leads out (eg, using small pliers) to fit the PCB footprints. Ensure the flat sides face as shown.

Construction continues with the installation of the 3-way pin header for JP1 and the 10-way and 14-way box headers, CON9 and CON10. These sockets must be installed with their slotted keyways oriented as shown. Remember that you don't need CON9 for the standalone version, but you do need CON11, so now is a good time to fit it.

Finally, complete the assembly by installing the six relays, the stereo RCA input sockets and the two vertical RCA output sockets. The red vertical RCA socket goes on the left and the white socket on the right. These colours then match those for the CON1-CON6 stereo sockets.

Once you've finished soldering the parts to the board, plug the programmed microcontroller (IC1) into its socket, ensuring that it is oriented correctly.

Front panel control board assembly

There are only a few parts on the control board but be careful to install the parts on the correct side of the PCB. The component footprints are screen printed on the side they should be installed. Pushbutton switches S1-S6 and IRD1 are on one side (the underside, as shown in Fig.20), and the 14-way IDC header CON12, the resistors and 100µF capacitor are on the other (top side).

IRD1, the 100µF capacitor and 100Ω resistor are not required when the *Audio Selector* is part of a *Preamplifier*.

Fit the pushbuttons first but note that they must be installed the right way around. These have kinked pins at each corner plus two straight pins for the integral blue LED. The anode pin is the longer of the two, and this must go in the hole marked 'A' on the PCB (towards CON12).

Once the pins are in, push the buttons all the way down so that they sit flush against the PCB before soldering their leads. IDC header CON12 can then be installed on the other side of the board, with its keyway notch towards the bottom.

IRD1, the 100Ω resistor and the 100µF capacitor should now be fitted, if building the standalone version. The

100Ω resistor and 100µF capacitor are mounted on the same side as CON12, while IRD1 is mounted on the pushbutton side, with its lens in line with the switches. The leads are bent at right angles, and it is mounted so that IRD1 is at the same height as the buttons.

Parts list – Six Input Audio Selector

Main board and Control board

1 double-sided PCB, code 01110191, 165 x 85mm
1 double-sided PCB, code 01110192, 106 x 36mm
  Both PCBs are available from the PE PCB Servce
6 PCB-mounting DPDT relays with 5V DC coil (RLY1-RLY6)
  [Altronics S4147]
6 PCB-mounting dual vertical RCA sockets (CON1-CON6)
  [Altronics P0212]
1 white vertical PCB-mount RCA socket (CON7)
  [Altronics P0131]
1 red vertical PCB-mount RCA socket (CON8)
  [Altronics P0132]
2 14-pin PCB-mount vertical IDC headers (CON10,CON12)
  [Altronics P5014]
6 PCB-mount pushbutton switches with blue LEDs (S1-S6)
  [Jaycar SP0622, Altronics S1173]
2 ferrite beads (FB1,FB2)
  [Jaycar LF1250, Altronics L5250A]
1 3-way pin header, 2.54mm spacing (JP1)
1 jumper shunt/shorting block (JP1)
1 18-pin DIL IC socket (for IC1)
4 M3 x 12mm nylon tapped spacers
4 M3 x 6.3mm nylon tapped spacers
16 M3 x 6mm panhead machine screws
2 14-pin IDC line sockets [Altronics P5314]
1 350mm length of 14-way ribbon cable

Semiconductors

1 PIC16F88-I/P microcontroller programmed with 0111019A.
  HEX (IC1)
6 BC337 NPN transistors (Q1-Q6)
6 1N4004 1A diodes (D1-D6)

Capacitors

1 100µF 16V PC electrolytic
1 100nF MKT polyester or multi-layer ceramic
2 470pF NP0/C0G ceramic or MKT polyester or MKP
  polypropylene
  [eg, element14 Cat 1005988]

Resistors (all 0.25W, 1% metal film)

1 10kΩ 6 2.2kΩ 12 100Ω

Extra parts for standalone version

1 3-pin infrared receiver; eg TSOP4138, TSOP4136 (IRD1)
1 7805 5V regulator (REG1)
1 1N4004 1A diode (D7)
3 100µF 16V PC electrolytic capacitors
1 2.2kΩ 0.25W 1% resistor
1 100Ω 0.25W 1% resistor
1 2-way screw terminal, 5.08mm spacing (CON11)
1 M3 x 6mm panhead machine screw and hex nut (for REG1)

Extra parts for connecting to Preamplifier

1 PIC16F88-I/P microcontroller programmed with 0111111M.
  HEX*
1 10-pin PCB-mount vertical IDC header (CON9)
  [Jaycar PP1100, Altronics P5010]
2 10-pin IDC line sockets
  [Jaycar PS0984, Altronics P5310]**
1 250mm length of 10-way ribbon cable**

** replaces IC5 in the Preamp described in April and May 2020*
*** not required if already part of pre-existing preamp*

You will also need a 'Universal' Remote Control (see text) – eg Altronics A012 or Jaycar AR1954 or AR1955

Making the cables

You need to make the interconnecting cables before you can test the *Audio Selector*. If you're building a standalone unit, you only need to make the 14-way cable which connects the two boards, shown at the bottom of Fig.21. Otherwise, make both the cables, including the 10-way cable that will connect back to the *Preamplifier* board.

If you're building this unit as an upgrade to an existing *Preamplifier* which already has the three-way input switcher, you should already have those cables.

Pin 1 is indicated on each socket by a small triangle moulded into the plastic, while wire 1 in each section of ribbon cable should be red. The red stripe of the cable must go to pin 1.

The best way to crimp the IDC connectors onto the cables is by using a dedicated IDC crimping tool, such as the Altronics T1540.

Alternatively, you can crimp them in a vice or using large pliers that have jaw protectors, or a woodworker's screw-adjust G clamp with the IDC connector sandwiched between two strips of timber.

Don't forget to fit the locking bars to the headers after crimping, to secure the cable in place. Having completed the cables, it's a good idea to check that they have been correctly terminated. The best way to do this is to plug them into the matching sockets on the PCB assemblies and then check for continuity between the corresponding pins at either end using a multimeter.

When complete, plug the 14-way cable into CON10 and CON12. The 10-way IDC cable (if used) connects between CON9 of the *6-Input Audio Selector* and CON7 on the *Preamplifier*.

Now place the shorting block on JP1 in the correct position, ie, to the left if you are building this as part of a *Preamplifier*, or to the right if it is a standalone unit.

Initial testing

Before programming the remote, it's worthwhile to power the unit up and check that the pushbutton, relays and LED indicators work as expected. If you're building it as a standalone unit, this is easily done by feeding 9-15V DC into CON11.

Otherwise, you will need to plug the unit into the *Preamplifier* board and power it in the usual way.

You can run the *Preamplifier* off an AC plugpack for testing, if you have one, via a rectifier and regulator board (see the last issue for options). You can switch to using a mains-based power supply once testing is complete.

Apply power and check that one LED lights up and you should hear a relay click on when power is applied. Press all the buttons and verify that you hear a click and that the LED in that button lights up, with all the others off.

If you want, you can feed an audio signal into each input in turn and check that it's only fed through to the output connectors when that input is selected.

Setting up the remote control

The remote control functions can now be tested using a suitable universal remote, as described below. By default, the *Audio Selector* expects remote control codes for a Philips TV. If this conflicts with any other equipment in your possession, you can switch it to use SAT1 or SAT2 instead.

If you have built the *Audio Selector* as a standalone unit, all you need to do to change modes is to press and hold S1

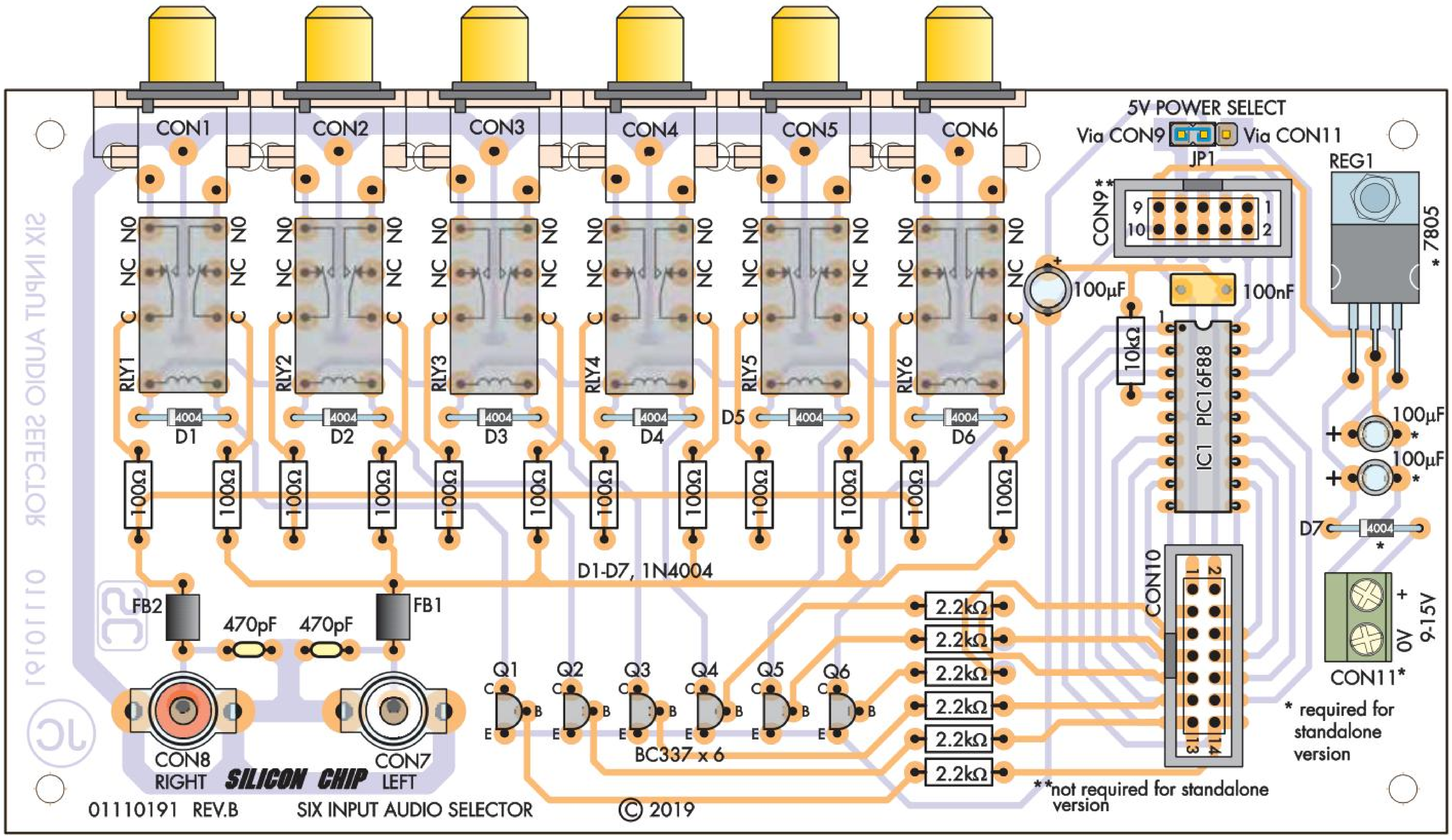

CON1
CON2
CON3
CON4
CON5
CON6
5V POWER SELECT
Via CON9
JP1
Via CON11
REG1
7805
CON9**
100µF
100nF
10kΩ
IC1 PIC16F88
RLY1
RLY2
RLY3
RLY4
RLY5
RLY6
NO
NC
C
4004
D1
D2
D3
D4
D5
D6
100Ω
100µF
D7
D1-D7, 1N4004
FB2
FB1
470pF
470pF
2.2kΩ
CON10
Q1
Q2
Q3
Q4
Q5
Q6
BC337 x 6
C
B
E
CON11*
0V
9-15V
+
* required for standalone version
**not required for standalone version
CON8 RIGHT
CON7 LEFT
SILICON CHIP
SIX INPUT AUDIO SELECTOR
01110191 REV.B
© 2019

Fig.19: follow this diagram and the photo below to build the main *Audio Selector* PCB. Make sure that the header sockets are correctly oriented, as well as IC1, the diodes and electrolytic capacitors. Note that CON1, D7, the two 100µF capacitors and REG1 are only installed if you are building it as a standalone unit.

on the pushbutton board during power-up to switch to using the SAT1 code, or S2 for SAT2. Pressing and holding S3 at power-up reverts to the default TV mode.

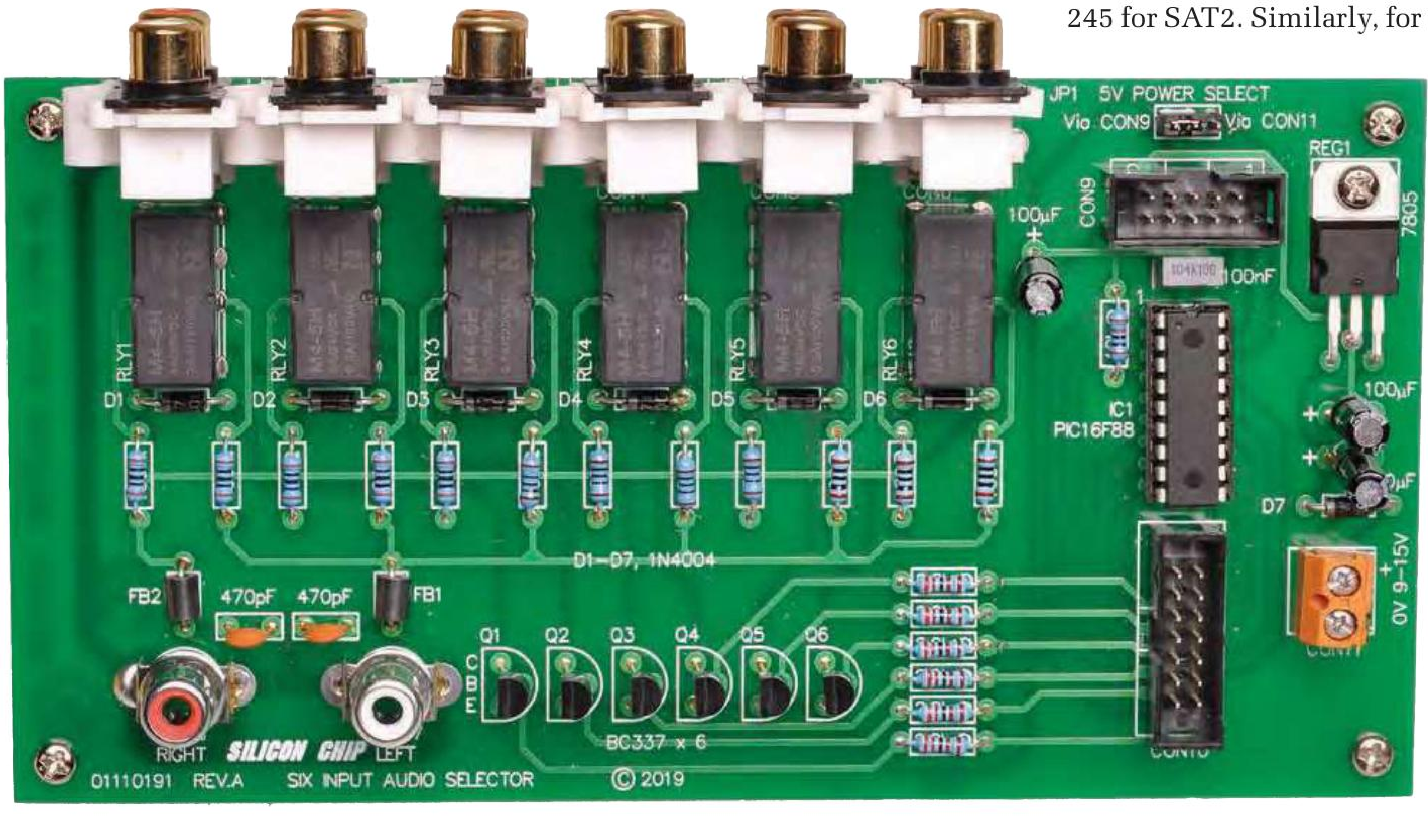
It's a bit more tricky if you're building this as part of a *Preamplifier* because the *Preamplifier* board has no way of reading the switch states. So in this case, you have to unplug the 10-way cable from CON7 on the *Preamplifier* board and then use a female-female jumper lead to temporarily short pins 1 and 9. Apply power, and wait a few seconds, then switch off, remove the jumper cable and plug the ribbon cable back in. That selects the SAT1 mode. If you need to select SAT2 mode, bridge pins 3 and 9 instead. To go back to the TV code, bridge pins 5 and 9.

Pin 1 is the one in the upper right-hand corner of CON7, nearest to the microcontroller, while pin 9 is in the upper left-hand corner. Pin 3 is immediately to the left of pin 1, and so on.

Programming the remote itself

Once you've chosen the mode, the correct code must be programmed into the remote control. This involves selecting TV, SAT1 or SAT2 on the remote (to agree with the microcontroller set-up) and then programming in a three or four-digit number to tell the remote control to send the codes that the unit is expecting to receive.

Most universal remote controls can be used, such as the Altronics A1012 and the Jaycar AR1955 or AR1954. For the Altronics A1012, use a code of 023 or 089 for TV mode, 242 for SAT1 or 245 for SAT2. Similarly, for the Jaycar


JP1 5V POWER SELECT
Via CON9
Via CON11
REG1
7805
CON9
100µF
100nF
IC1
PIC16F88
RLY1
RLY2
RLY3
RLY4
RLY5
RLY6
D1
D2
D3
D4
D5
D6
D7
100µF
D1–D7, 1N4004
0V 9-15V
FB2
470pF
470pF
FB1
Q1
Q2
Q3
Q4
Q5
Q6
BC337 x 6
RIGHT
SILICON CHIP
LEFT
01110191 REV.A
SIX INPUT AUDIO SELECTOR
© 2019

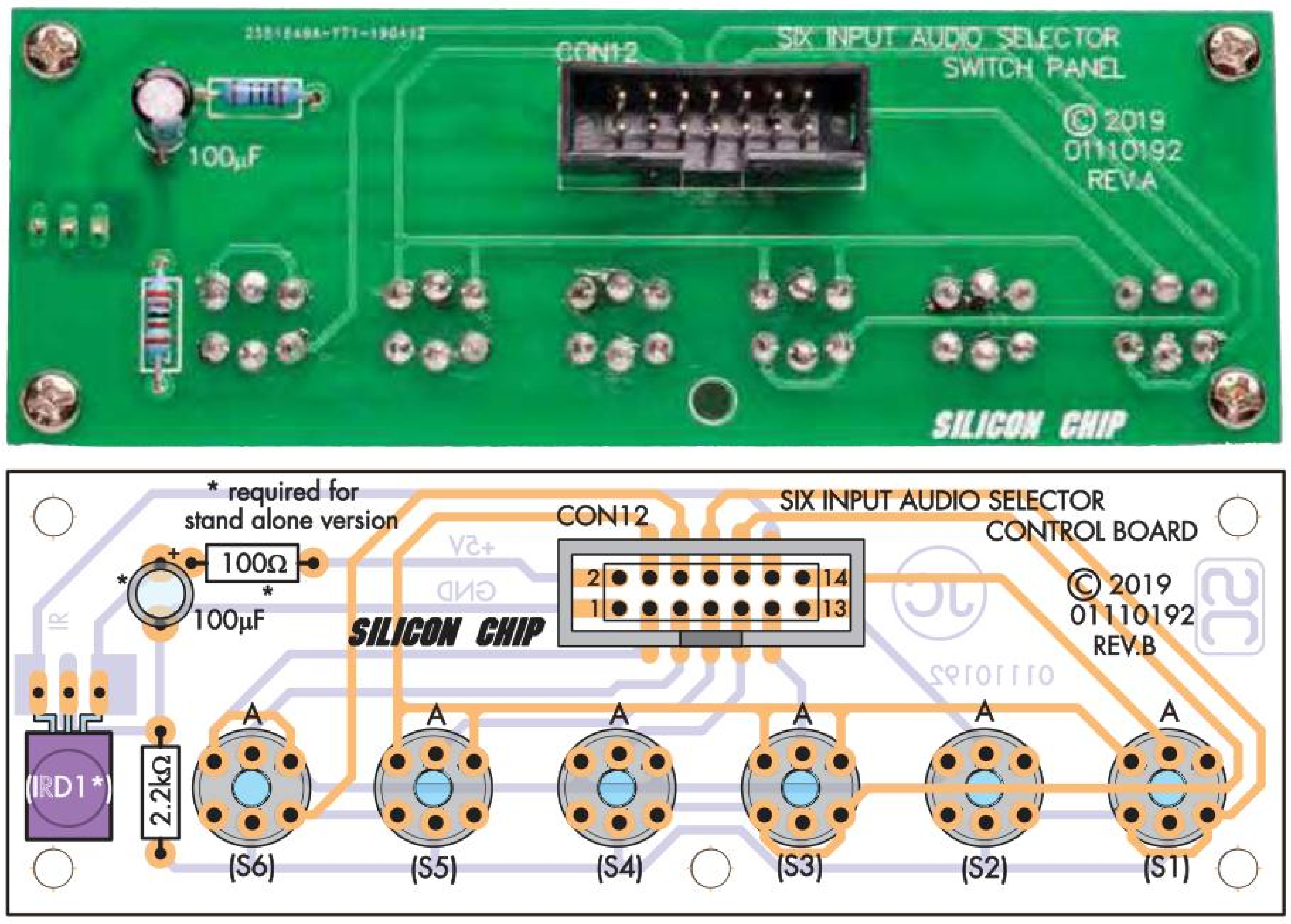
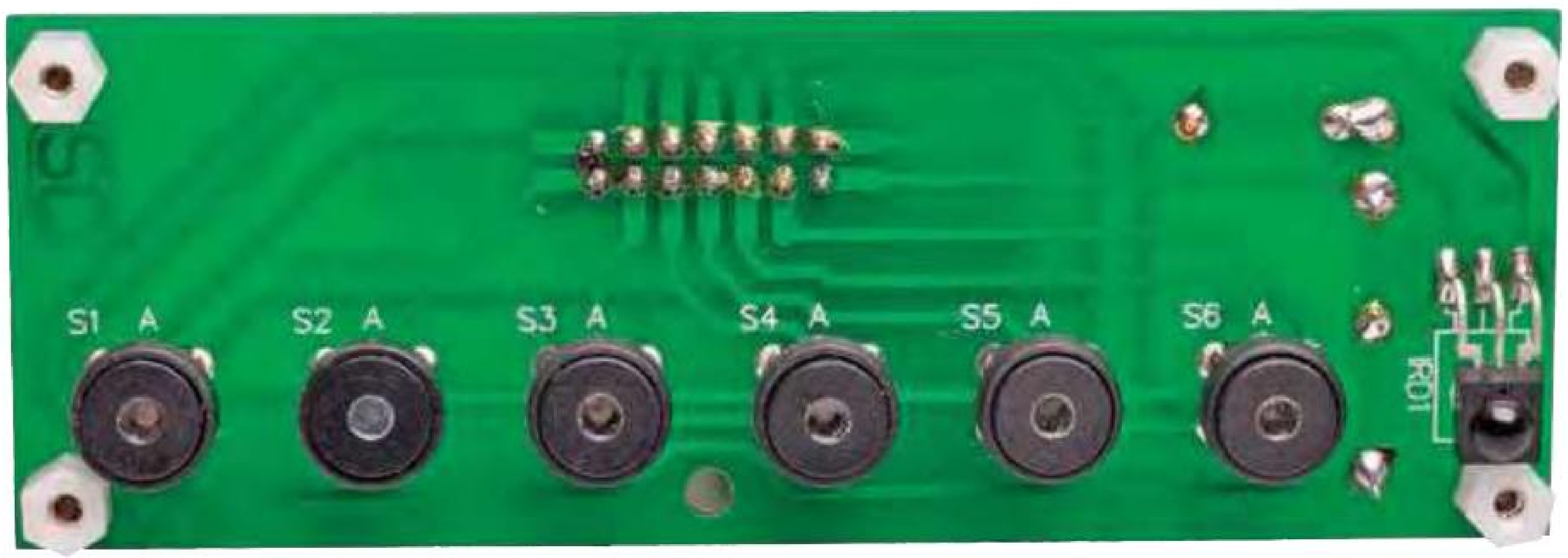

CON12
SIX INPUT AUDIO SELECTOR SWITCH PANEL
© 2019 01110192 REV.A
100µF
SILICON CHIP
* required for stand alone version
100Ω
100µF
IR
CON12
2
1
14
13
SIX INPUT AUDIO SELECTOR CONTROL BOARD
© 2019 01110192 REV.B
IRD1*
2.2kΩ
A
(S6)
(S5)
(S4)
(S3)
(S2)
(S1)

Fig.20: the six pushbutton switches and infrared receiver IRD1 (for the standalone version) are mounted on the back of the pushbutton board (which faces towards the front of the unit when installed) while the header socket, resistors and capacitor go on the top (with CON12's keyway towards S3 and S4). Make sure that the longer straight lead of each pushbutton goes to the pad marked 'A'.


S1 A
S2 A
S3 A
S4 A
S5 A
S6 A
IRD1

remotes, use code 1506 for TV, 0200 for SAT1 or 1100 for SAT2.

In the case of other universal remotes, it's just a matter of testing the various codes until you find one that works. Start with Philips devices as these are the most likely to work. There are usually no more than 15 codes (and usually fewer) listed for each Philips device, so it shouldn't take long to find the correct one.

Note that some codes may only partially work, eg, they might control the volume on the *Preamplifier* but not the input selection. In that case, try a different code. Also, some remotes may only work in one mode (eg, TV but not SAT).

Once you have set up the remote control, you can power the unit up and complete the testing process by pressing the buttons 1-6 in sequence and verifying that the corresponding LED lights up and the relays click over.

Troubleshooting

If you run into any problems, the most likely causes are improperly crimped or wired cables, mixed up or reversed components, bad solder joints or unprogrammed/incorrectly programmed microcontrollers.

These problems can all cause similar faults, so if it doesn't work the first time, go over the boards and compare them to Fig.19 and Fig.20. Ensure that all components have been installed correctly, then carefully inspect the solder joints to make sure you haven't missed any, you have used sufficient solder and there are no dry joints or solder bridges.

Presumably, you checked the continuity of your cables earlier, but if not, do so now. It's common to have problems with an IDC ribbon cable because the crimp has not been done with sufficient force for all the blades to cut through the insulation and make good contact with the copper inside.

If the unit responds to the 1, 2, 3, 4, 5 and 6 buttons on the remote, but the button switches don't work, check that the IDC ribbon cable to the pushbutton board has been plugged into the line sockets properly. Similarly, if the *Preamplifier* remote volume function works but not the remote input selection, check the cable from the *Preamplifier* board to the input selector board.

Since the cable from the *Preamplifier* board also supplies power to the other two boards, it's worthwhile checking that there is 5V between pins 5 and 14 of IC1 on the *Audio Selector* board. Also, check that JP1 is in the correct position.

If everything works except the remote control, check that it has fresh batteries. If it does, most likely it is not programmed for the code that the unit is expecting. Re-check that you have set up the *Audio Selector* board to the right code, and programmed the remote control with the correct corresponding code.

Mounting it in the case

If building a standalone unit, you will need to choose a case large enough to mount both boards; ie, at least 200mm wide and 150mm deep. If powering it from a plugpack, fit a chassis-mount concentric DC socket and wire it up to CON11.

The 12mm tapped spacers can be used to mount the main board in the bottom of the box, while the 6.3mm tapped spacers are used to mount the front panel board after drilling six 9mm-diameter holes spaced 15.1mm apart for S1-S6.

Once you've made those holes, you can temporarily fit the front panel board and mark out the locations of the four mounting holes, then drill them to 3mm.

You may want to use black machine screws to attach the front panel board to the front of the case if using a black case, so they are not so visible, and possibly even use countersink head screws. It would also be a good idea to attach some rubber feet to the bottom of the case.

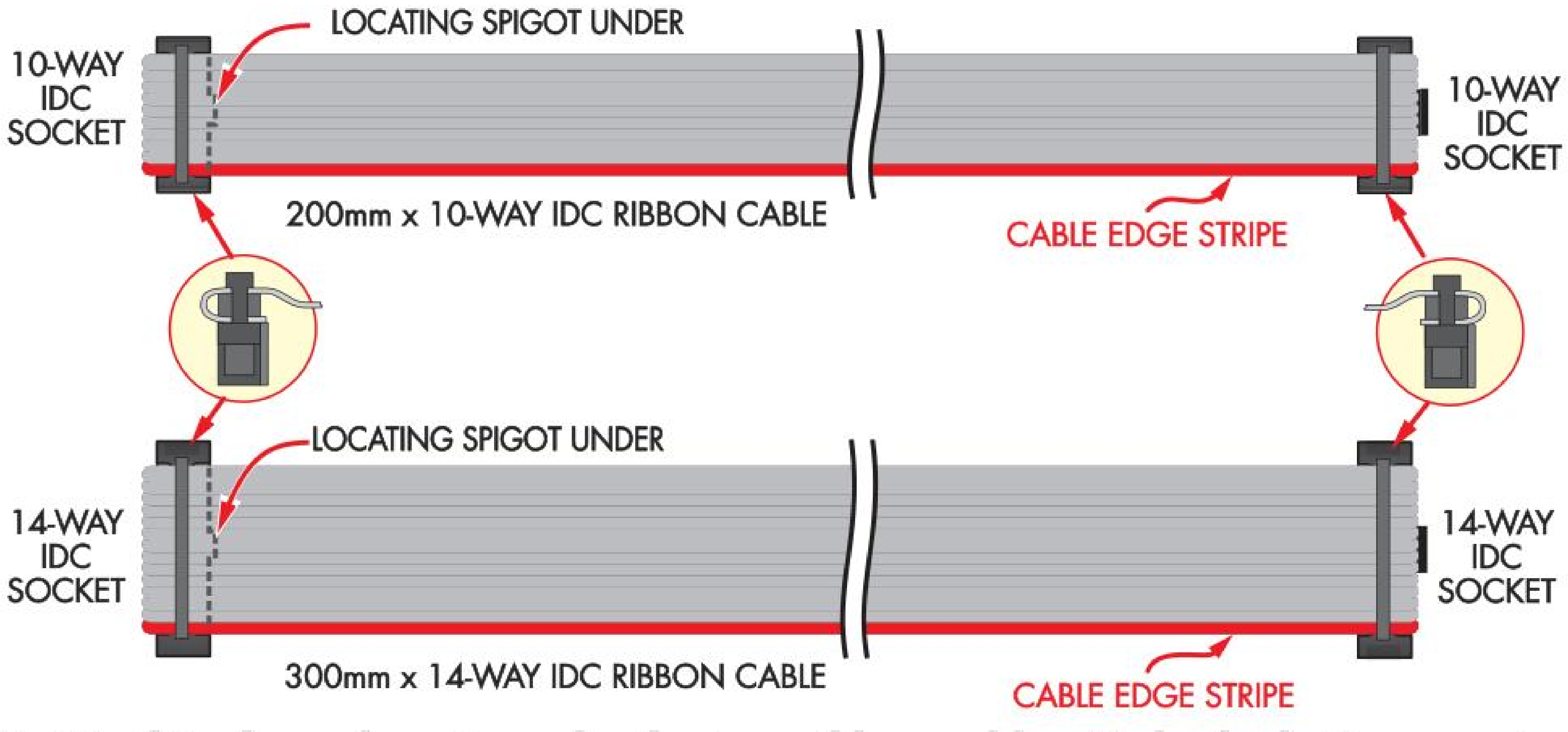

LOCATING SPIGOT UNDER
10-WAY IDC SOCKET
10-WAY IDC SOCKET
200mm x 10-WAY IDC RIBBON CABLE
CABLE EDGE STRIPE
LOCATING SPIGOT UNDER
14-WAY IDC SOCKET
14-WAY IDC SOCKET
300mm x 14-WAY IDC RIBBON CABLE
CABLE EDGE STRIPE

Fig.21: this shows how to make the two ribbon cables. Only the bottom one is required if building the standalone unit. If upgrading an existing *Preamplifier* which already had a 3-input switcher, you should already have both cables.

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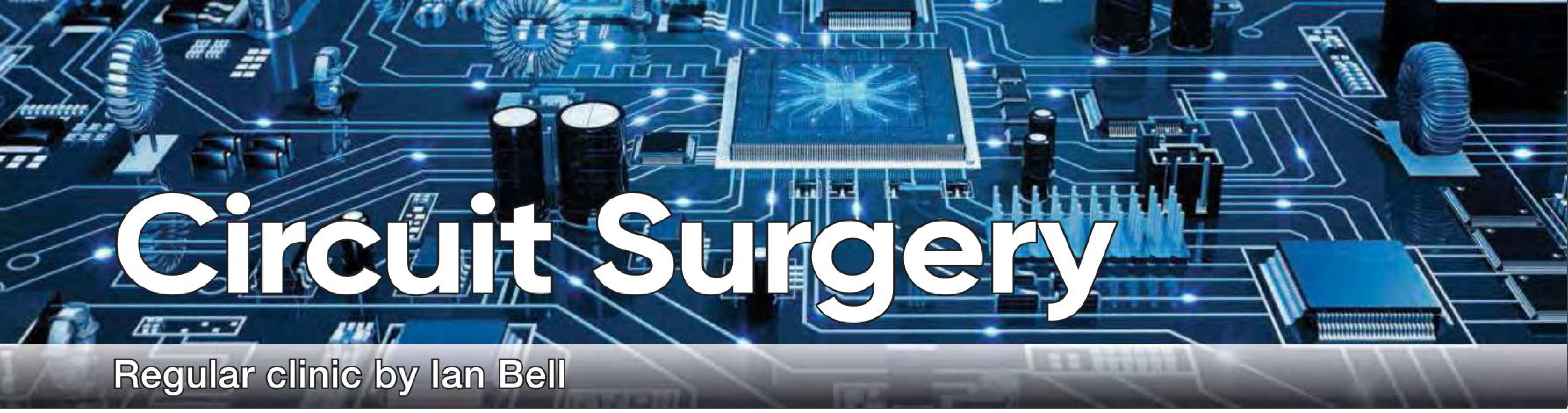


Circuit Surgery

Regular clinic by Ian Bell

Class-D, G and H amplifiers

Regular PE author Julian Edgar suggested this month's topic after reading an article by Mike Spence on Texas Instruments' support forum discussing 'look-ahead' voltage-rail boosting in class-D audio amplifiers (these circuits are also known as class-G and H amplifiers). There was also a post on amplifier classes recently from Tom Mot on the *PE* forum: 'I'm fairly new to speaker amplifiers, but I understand the different classes (ie, Class-A, Class-AB, Class-D). But how would I identify the class of an amplifier, for instance if I was buying an amplifier online and the class was not mentioned (which often seems to be the case, from my experience) – how could I know the class of the amp?'

In direct response to Tom's post we cannot say much beyond the reply on the forum from Richard Gabric; that if the information is not supplied it would be difficult to know, but class D is widely used in modern designs. This may be particularly likely for lower-costs designs, and portable personal electronics, but class D is also used in high-quality amplifiers. In this article we will look briefly at the other classes used in audio (that is A, B and AB – C, E and F are mainly used for radio-frequency signals) before concentrating on D, G and H.

Classes A, B and AB

A class-A amplifier is based on a single transistor operating as a linear amplifier – for example, the circuit in Fig.1. The circuit requires biasing (not shown) to put the transistor into its forward active mode, and set up at about half the supply voltage at the output with no signal present. This is a relatively simple circuit, but the bias conditions require the transistor to be conducting continuously with no signal, which wastes a significant amount of power in proportion to that provided to the load. This is characterised as amplifier efficiency – the ratio of the power actually delivered to the load (the loudspeaker in an audio amplifier) to that taken from the supply. Class-A amplifiers have poor efficiency.

To improve efficiency it would be possible to bias a single transistor so that it was not conducting when there was no signal – increasing input voltage would switch the transistor on, allowing it to act as an amplifier. Unfortunately, this would result in only half of the signal being amplified – a change of the signal in the opposite direction would not switch the transistor on, and no amplification would occur. This problem can be overcome by using a pair of complementary transistors – one conducts for the positive half of the waveform and the other for the negative. This is the class-B amplifier, which is shown in Fig.2. The circuit is much more efficient than the class-A amplifier, but suffers from a problem called 'crossover distortion'. When the signal voltage is small both transistors are off, so there is dead band in the output for low signal voltages, which means that the amplifier does not fully reproduce the signal waveform shape at its output.

Class-AB amplifiers overcome crossover distortion by applying a bias voltage to each transistor in a circuit similar to class B. The bias ensures that both transistors are just conducting with no signal. Even a small change in the signal away from zero will be amplified by one of the transistors, reducing crossover distortion. The no-signal bias level can be much smaller than for class-A amplifier, thus providing better efficiency. Class AB is a compromise between classes A and B and can be designed to set the desired level of trade-off between efficiency and linearity.

Note that the circuits in Fig.1 to 3 show the basic circuit topology, but not details of the circuitry required to create a working design.

Efficiency and class D

Class-D amplifiers are more efficient than class A, B and AB. This has been the key driving force in the significant increase in their use in recent years. The need to maximise battery life in devices such as mobile phone, and the increasing awareness of the need for greener technology, both favour energy-efficient approaches to circuit design. Efficient electronics also tends to be physically smaller and lighter, which is another significant advantage in portable devices, and in achieving modern slim aesthetics in mains-powered products.

Amplifiers waste any power that is dissipated in the output transistors. Ideally, all the power from the supply should go to the load; however, linear amplifiers (A, B and AB) involve some voltage being dropped across the transistor (collector-emitter (CE), or drain-source (DS)) while they are conducting, which leads to power dissipation in the transistor (equal to $V_{CE}I_{CE}$ or $V_{DS}I_{DS}$). As we have seen, depending

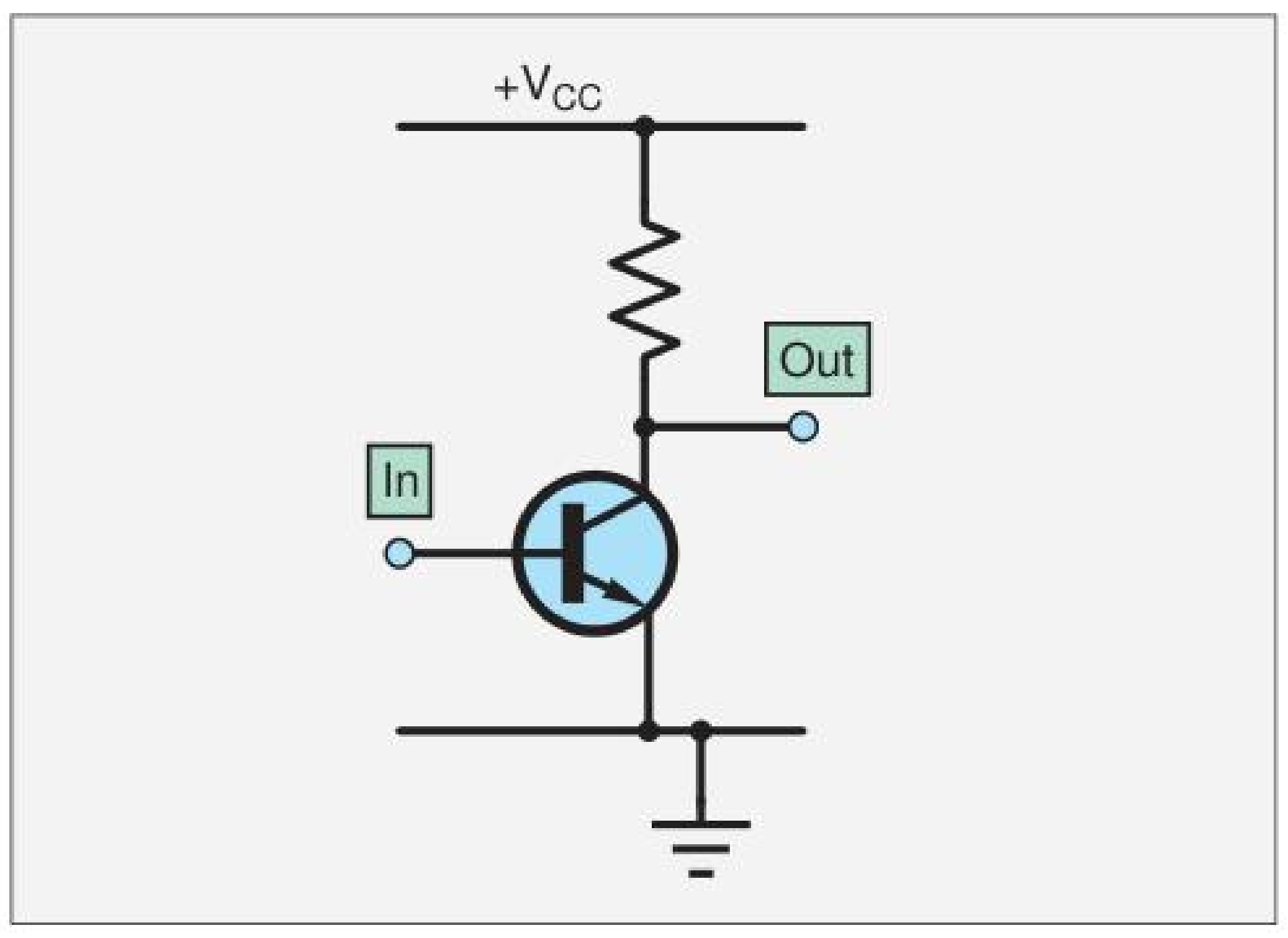


Fig.1. Basic class-A amplifier architecture.

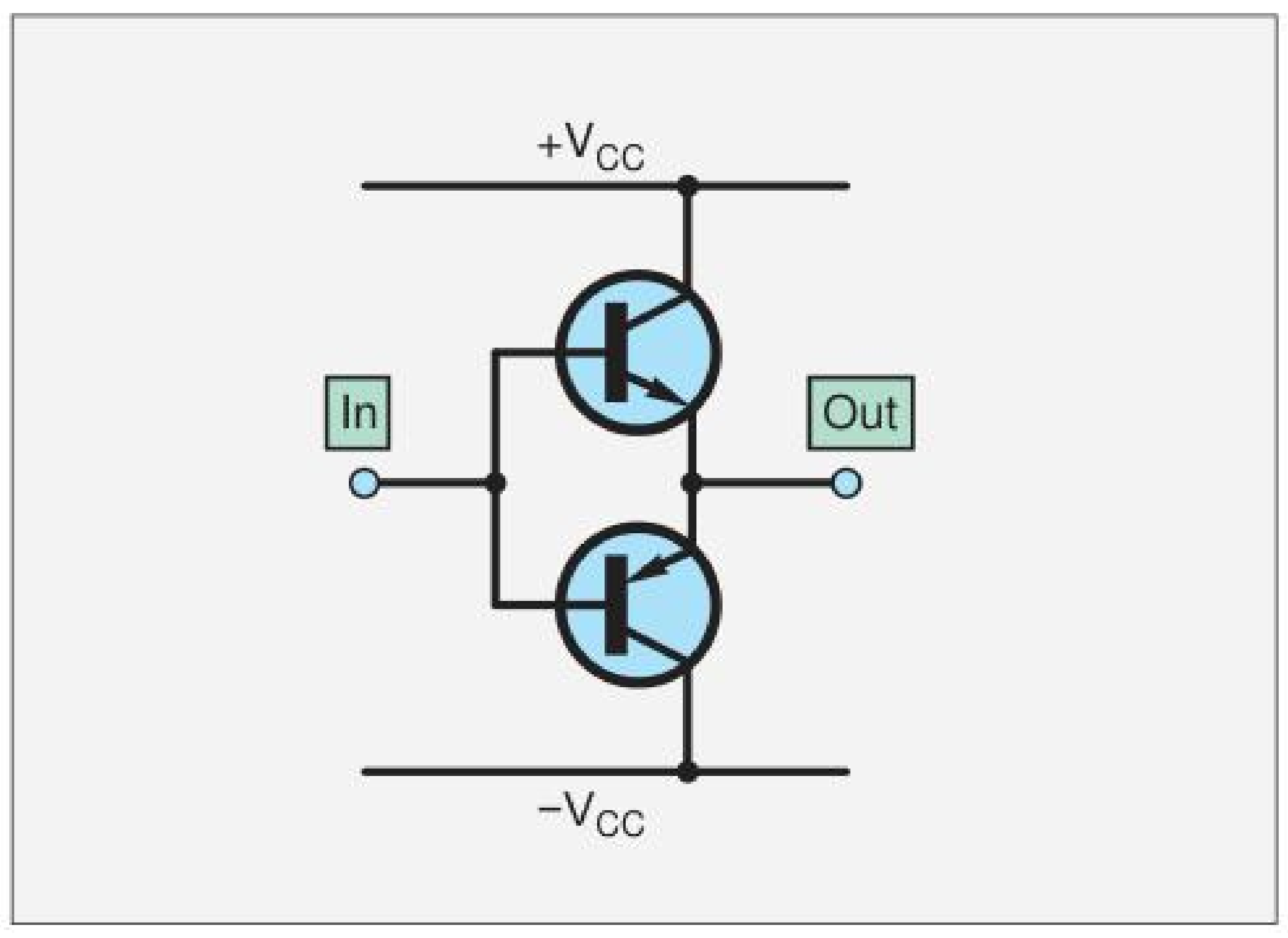


Fig.2. Basic class-B amplifier architecture.

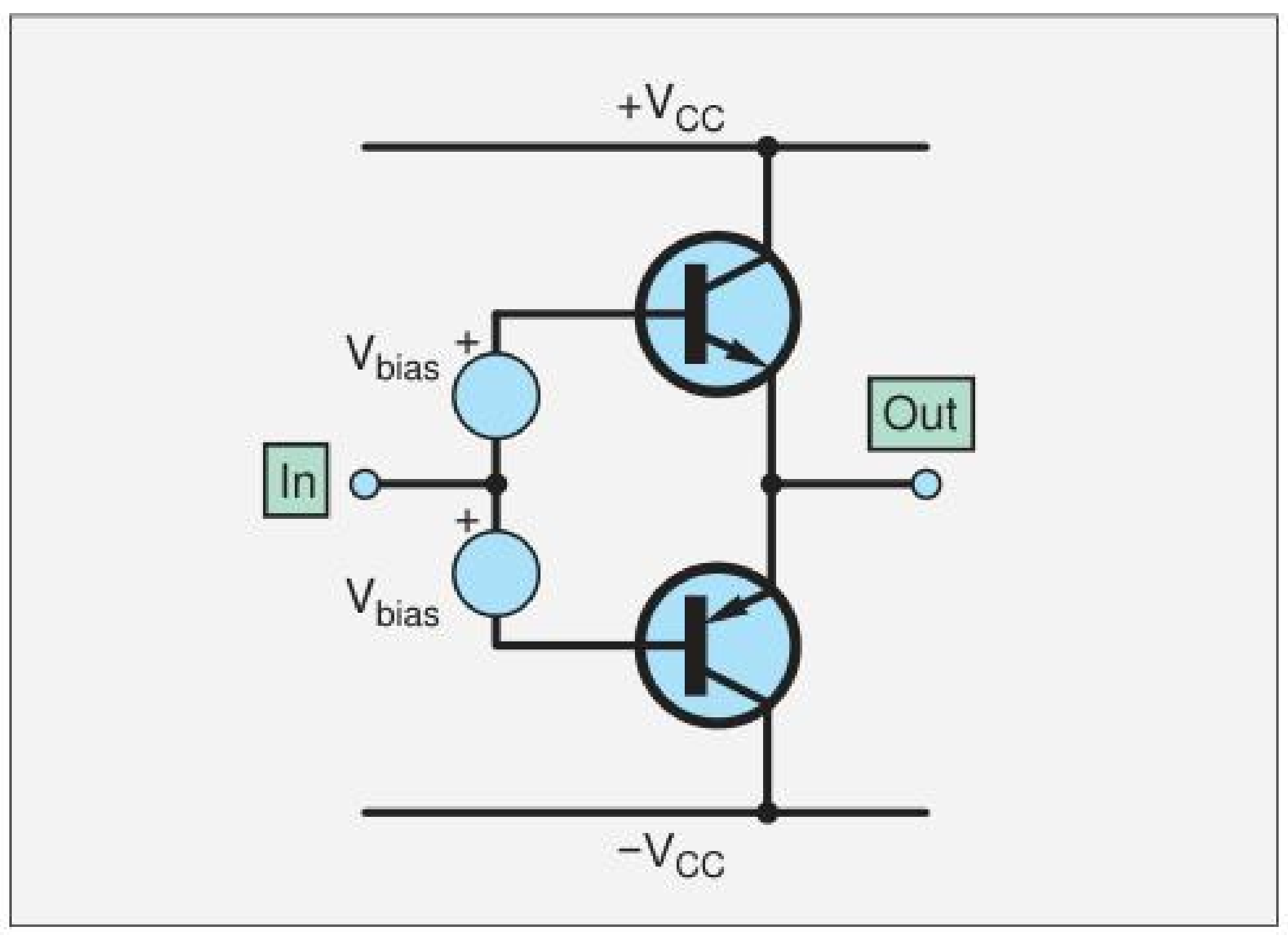


Fig.3. Basic class-AB amplifier architecture.

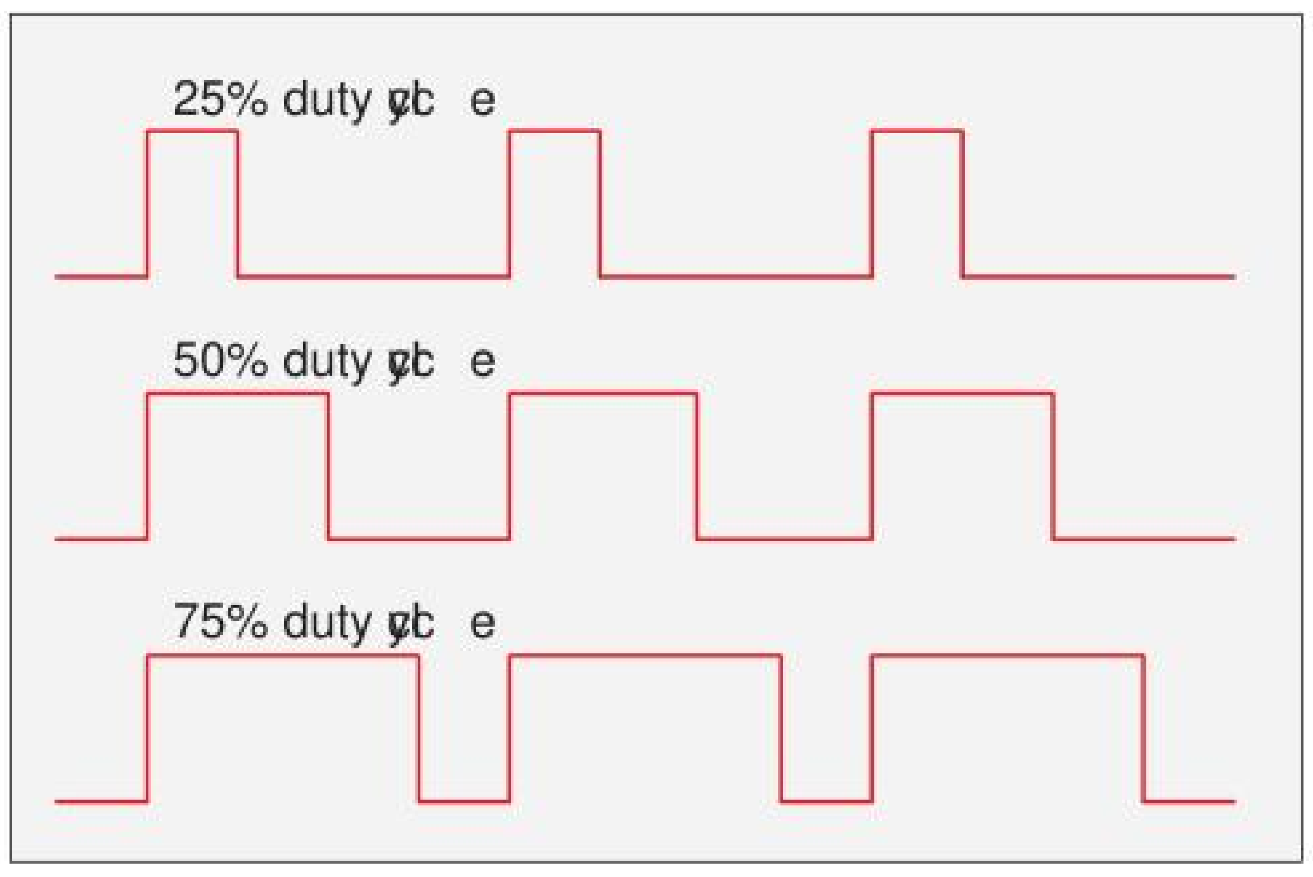


Fig.4. Fundamentals of duty cycle.

on the circuit design, the transistors may also have a bias current that means they are conducting with no signal present – this leads to continuous power wastage even when no signal is present.

Class-D amplifiers achieve their high efficiency by switching their output transistors (which are usually MOSFETs) fully on and fully off. In the off state, very little current flows through the transistor – I_{DS} is close to zero, so $V_{DS}I_{DS}$ is very small. A MOSFET operated as a switch has a low voltage across it in the on state – V_{DS} is close to zero, so $V_{DS}I_{DS}$ is again very small.

The switching nature of the class-D amplifier means that its output is like a square wave, or more specifically a train of pulses, so how can it reproduce an audio (music or speech) signal which is nothing like a square wave? The answer is that the pulses are produced (the transistors are switched) at much higher frequencies than the audio signal and are manipulated in such a way that if the pulses are passed through a low-pass filter, which removes frequencies at the pulse-switching rate, then the output of the filter will be the audio signal. The manipulation of the pulses is referred to as 'modulation'.

There is more than one modulation technique that can be used for class-D amplifiers. Two widely used approaches are pulse-width modulation (PWM) and pulse-density modulation (PDM). These names are descriptive of what happens. In PWM, the width of pulses at a fixed frequency is varied in sympathy with the audio signal. In PDM, the number of fixed-width pulses per unit time is varied. In both cases, for a fixed pulse height (voltage), the average value of the modulated signal (the pulse train) is equal to the modulating signal (the audio) and can be obtained by a suitable low-pass filter. We will look at PWM in more detail as it is the simplest case, although many modern class-D amplifiers actually use PDM.

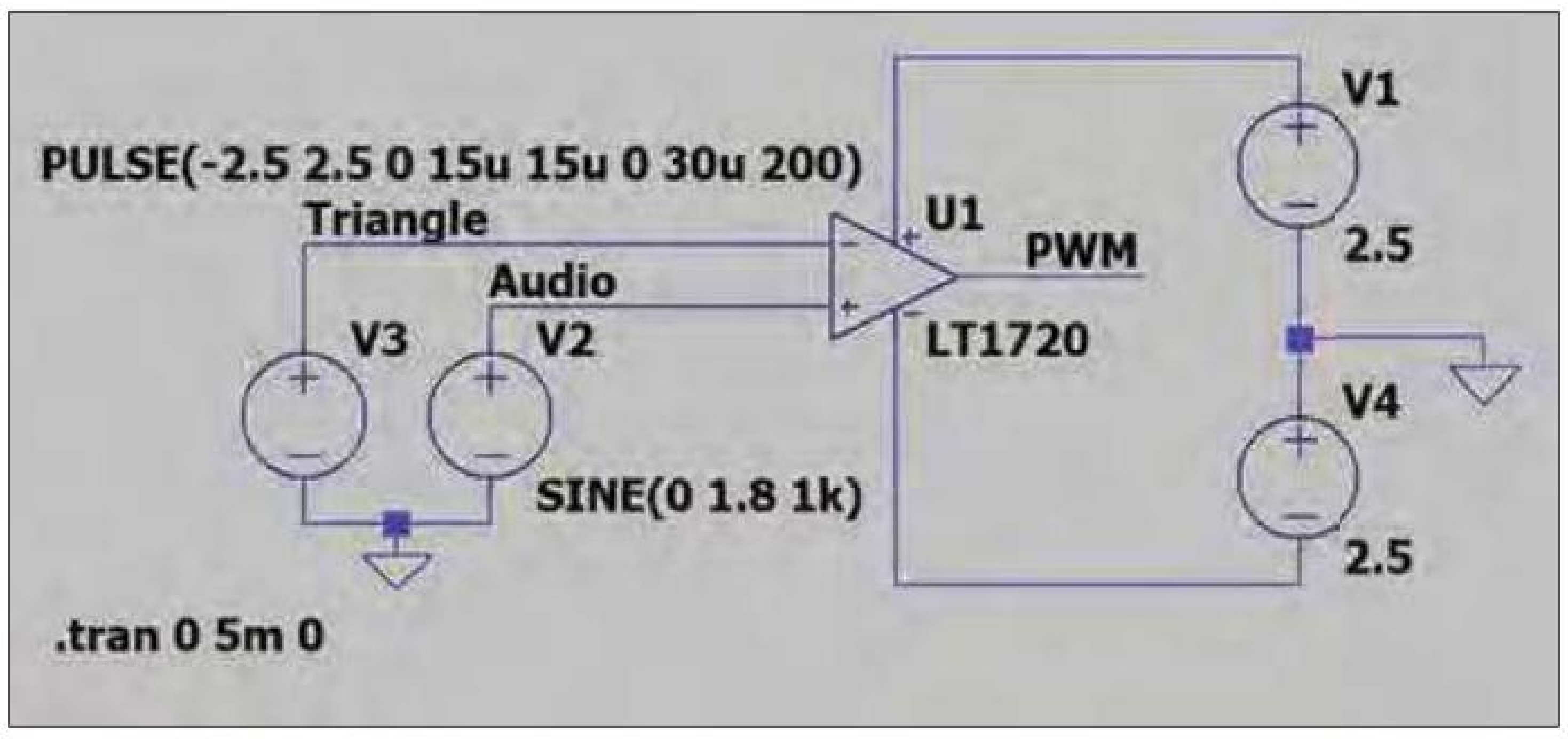


Fig.6. LTspice schematic for a PWM modulator concept circuit.

Pulse-width modulation (PWM)

The width of pulses produced at a fixed frequency (repetition rate) can be described in terms of their duty cycle (see Fig.4). Duty cycle is the proportion of the cycle period that the pulse is high for. A pulse train with a 50% duty cycle is an ideal square wave, which is on for exactly half the period. Lower duty cycles have proportionally shorter pulses and higher ones have longer pulses, as shown in Fig.4. A pulse width modulator generates a train of pulses such that the duty cycle of each pulse is set by the modulating signal value at the instant each pulse is produced. Duty cycle has a limited range of 0 to 100%, so excessive signal values will run out of duty cycle range – this is similar to a linear amplifier clipping large signal peaks due to its output range being limited by the supply voltage.

As indicated above, the modulating signal can be recovered from the PWM pulse train by averaging the pulse signal voltage over time (low-pass filtering). The waveforms in Fig.5 illustrate the process of averaging a PWM signal. A constant frequency (1kHz) and voltage (1V) pulse waveform (red trace) starts with a 25% duty cycle (the pulse is 1V for 25% of the time and 0V for 75% of the time). After 30ms the duty cycle increases to 50% (equal on and off times) and at 60ms it increases to 75%. The other trace (blue) shows an average value obtained by low-pass filtering the pulse waveform. This represents signal power delivered to the load in a PWM system.

As can be seen in Fig.5, when the PWM duty cycle changes, the averaging process means that it takes a while for the power level to settle down to the new value – this is normal for a low-pass filter with a step input (the duty cycle has undergone an instantaneous changes in this example, whereas most audio signals would change more smoothly). There is also a very small amount of ripple in the level with each pulse in Fig.5. The exact waveforms in a real system will depend on pulse frequency and the properties of the filtering process. Fig.5 is for illustrative purposes only and does not aim to represent a specific system.

PWM uses and filtering

In addition to class-D amplifiers, PWM is used in a wide variety of applications including switch-mode power supplies, and motor speed and LED brightness control. In some cases the load itself low-pass filters the pulses to provide the averaging function. A simple example of this is applying power to a heating element where the element and/or the item being heated has a thermal time constant much longer than the pulse duration. For control of LED brightness for human observation, the LEDs are actually switched on and off (flashed) with the PWM pulses, so the averaging processing occurs within the observer due to persistence of vision. More specifically, the PWM pulses to the LED must be faster than the flicker fusion frequency, which is the frequency at which a modulated light source appears to have constant intensity to a human observer.

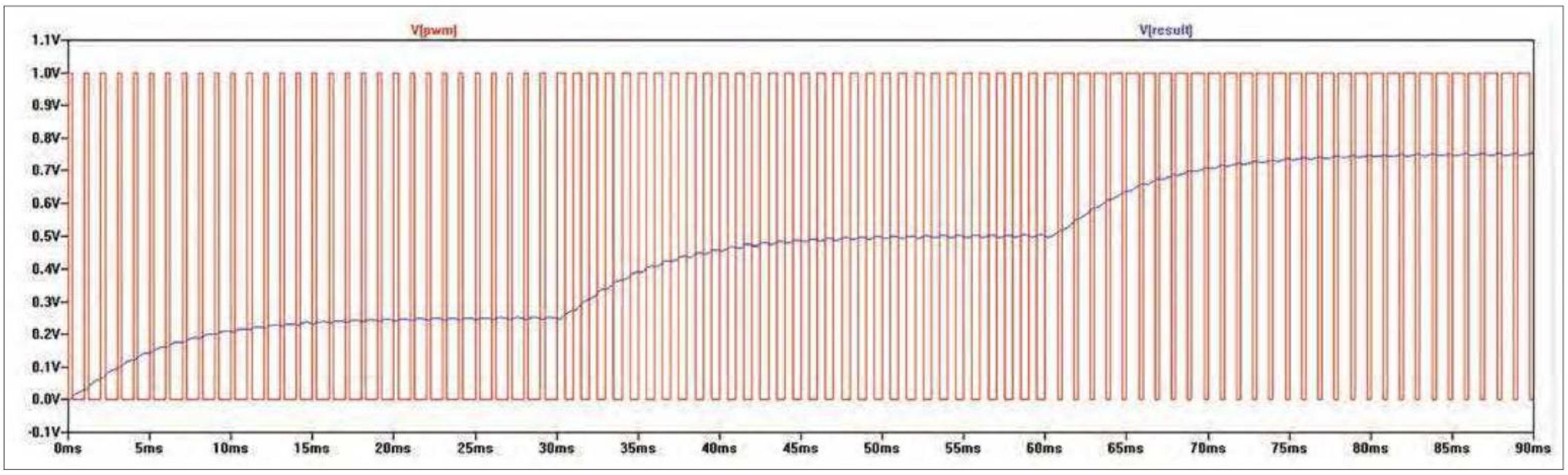


Fig.5. Example PWM waveform.

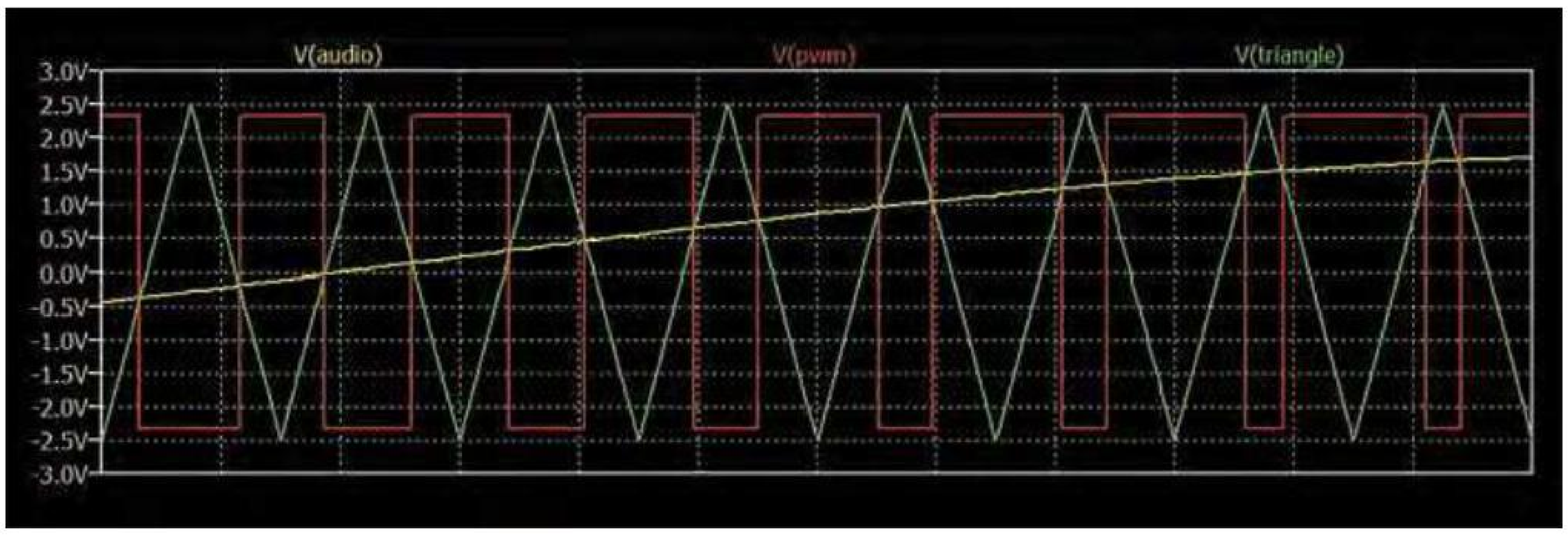


Fig.7. Relationship between the audio, triangle and PWM signals for a PWM modulator (simulation of the circuit in Fig.6). Each triangle cycle lasts 30µs.

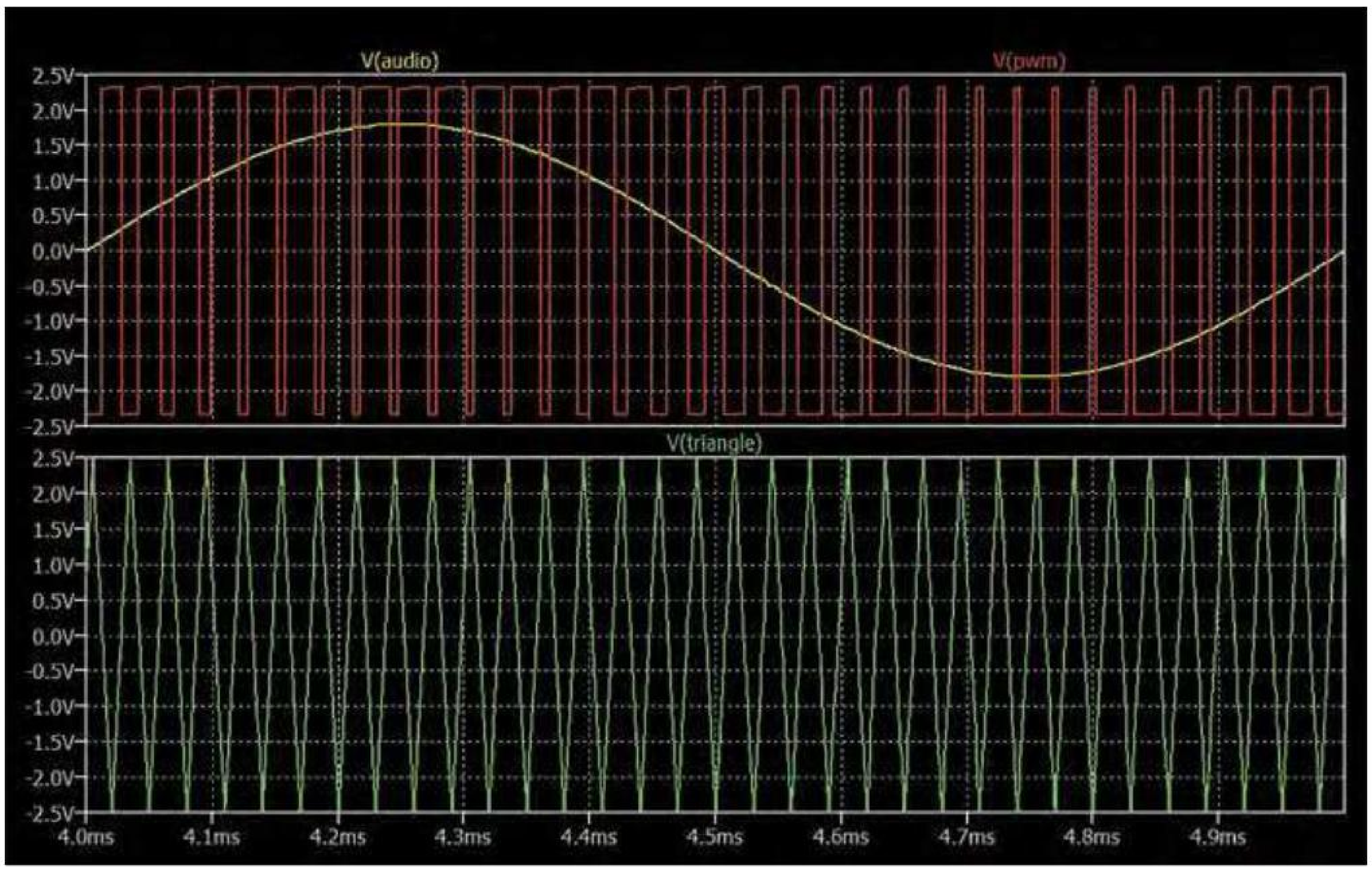


Fig.8. Simulation of the circuit in Fig.6 showing a complete cycle of the audio sinewave.

For class-D audio amplifiers the loudspeaker and human ear are able to provide the filtering required to recover (demodulate) the original audio signal. An important design requirement is that to avoid potentially damaging effects, loudspeakers should not be driven with high-amplitude square waves *in the audio range* (20Hz to 20kHz). Fortunately, PWM pulse-train frequencies of hundreds of kilohertz to megahertz cause very little direct cone movement, and speakers will respond to the average signal level – that is the original audio signal. Furthermore, the human ear also acts as a filter for signals above about 20kHz, which is well below the pulse frequency. However, class-D amplifiers using relatively low pulse frequencies may require an LC filter for demodulation.

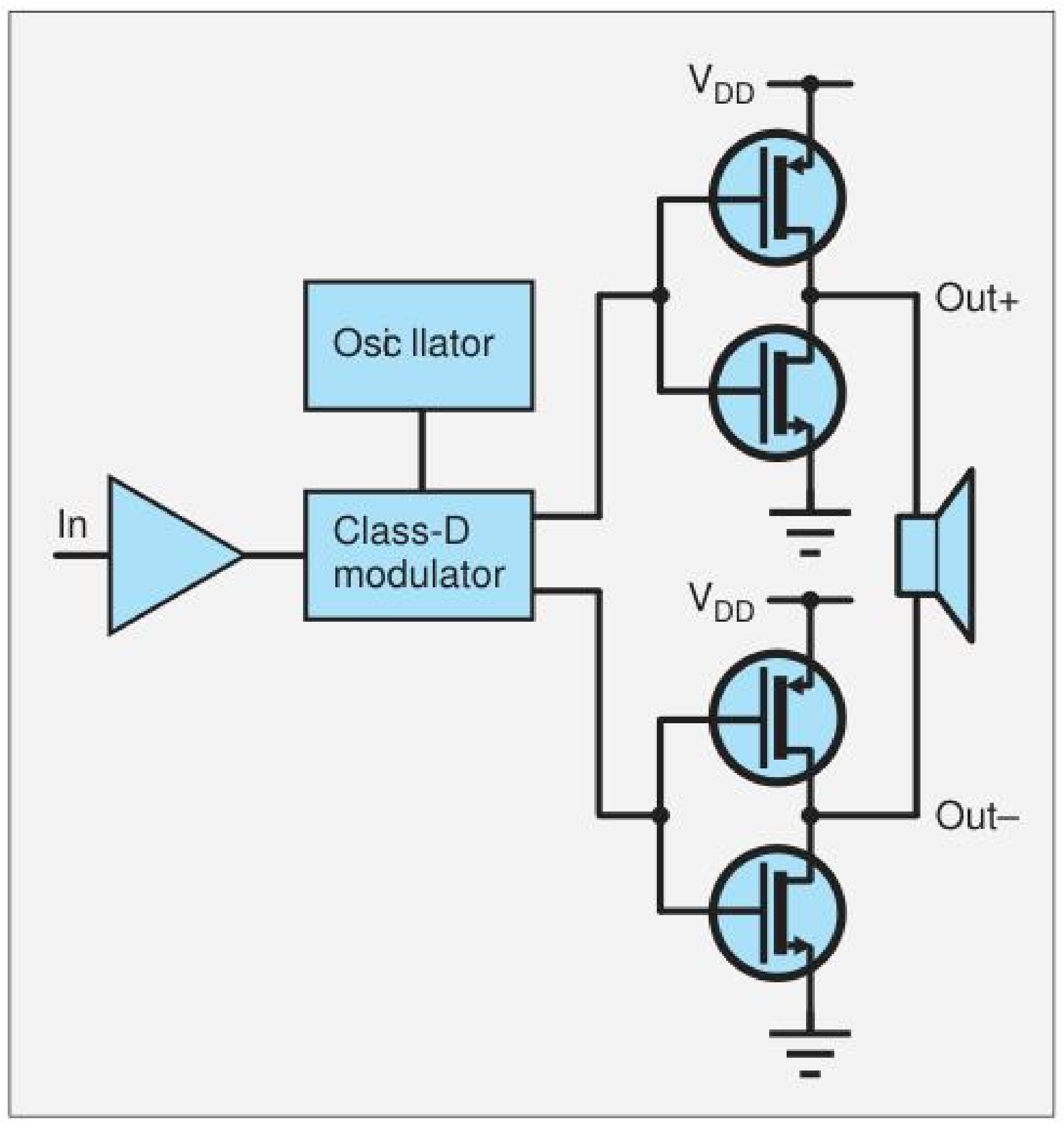


Fig.9. Outline schematic of a filterless class-D amplifier.

Filters may also be required on class-D amplifier outputs for reasons other than demodulation. For example, high-frequency switching can result in an amplifier producing EMI (electromagnetic interference) if an unfiltered PWM signal is sent down relatively long speaker wires without filtering. Often, ferrite beads can be used for EMI suppression rather than larger and more expensive LC filters.

Class-D amplifier circuit structure

The basic structure of a class-D modulator is shown in the LTspice schematic in Fig.6. This is not intended as a practical design – it illustrates the basic concept, and LTspice provides a convenient means of drawing the waveforms. The circuit comprises a comparator driven by the audio signal and a triangle wave – both waves have zero DC offset. The audio signal is represented by a 1kHz sinewave of ±1.8V amplitude. The triangle waveform has the same amplitude as the supply voltage, ±2.5V. The triangle wave frequency is 33kHz, much lower than a typical real class-D amplifier switching frequency, but better for illustration of the general shape of the waveforms.

The comparator will switch on (produce a high output voltage) when the audio signal is more positive than the triangle-wave voltage. So for more positive audio voltages the output will be on for a greater proportion of the triangle wave cycle (see Fig.7). Thus, the output duty cycle will vary from 0% for an audio input voltage of –2.5V to 100% for an audio input of +2.5V. The example audio signal has a lower amplitude than these extremes, so that the modulator switches throughout the audio waveform cycle (see Fig.8).

Fig.9 shows an outline schematic of a filterless class-D amplifier. Typically, the modulator has complementary outputs which drive two MOSFET push-pull switches in an H-bridge arrangement, as shown. In practice, the circuit may be more complex – for example, with feedback from the output to an error amplifier before the modulator in order to improve output signal quality. If a demodulation filter is used it will typically be a balanced second-order LC filter, as shown in Fig.10. Note that the circuit in Fig.9 is a fundamentally analogue design – the 'D' in 'class D' does not mean 'digital'. In digital audio systems the PWM (or PDM) output can be digitally generated, however the audio may still be converted to analogue (by a DAC) for modulation because fine control of the pulse modulation requires digital clock frequencies many times faster than the pulse rate.

Class-G amplifiers

At a given supply voltage, the efficiency of all the amplifier classes discussed above reduces for low signal levels – a significant proportion of the wasted power is independent of the signal level, but is dependent on the supply voltage, so a relatively high proportion is wasted at low signal levels. For typical audio signals, such as music, the level may be relatively low for a significant proportion of the time, and, in typical usage, amplifiers may be run at relatively low volumes much of the time; only being turned up loud occasionally. For the lower level signals the amplifier could operate at a lower supply level, and would be more efficient, but then would not be able to

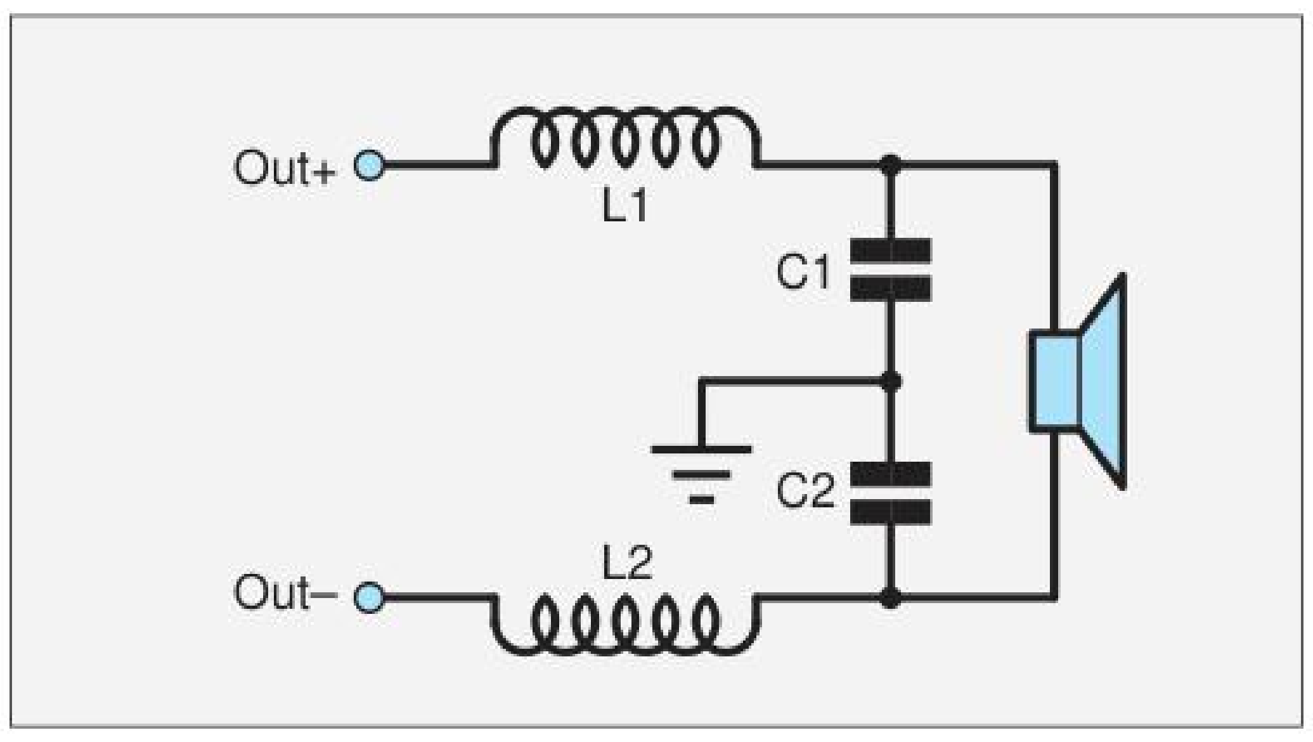


Fig.10. Typical class-D amplifier output filter (if used).

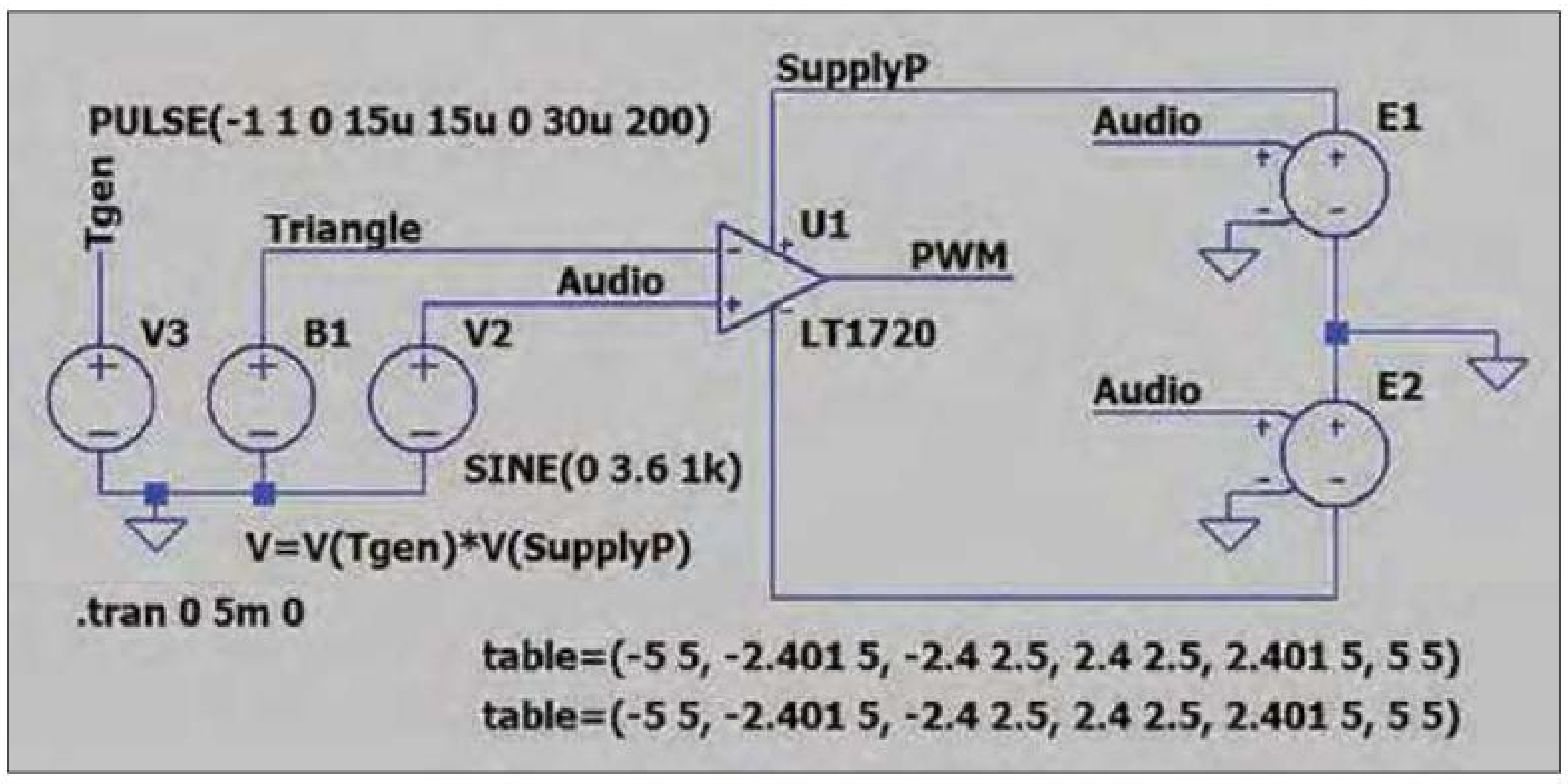

SupplyP
PULSE(-1 1 0 15u 15u 0 30u 200)
Audio
E1
Tgen
Triangle
U1
PWM
Audio
V3
B1
V2
LT1720
Audio
E2
SINE(0 3.6 1k)
V=V(Tgen)*V(SupplyP)
.tran 0 5m 0
table=(-5 5, -2.401 5, -2.4 2.5, 2.4 2.5, 2.401 5, 5 5)
table=(-5 5, -2.401 5, -2.4 2.5, 2.4 2.5, 2.401 5, 5 5)

Fig.11. LTspice schematic to generate illustrative waveform for a class-G amplifier based on a class-D amplifier.

correctly reproduce louder passages of music, or satisfy the user when high volume was required.

A solution to this supply/efficiency/output issue is to run the amplifier at a relatively low supply voltage most of the time, but switch the supply to a higher voltage ('boost' it) when a higher output power is needed. Amplifiers operating in this way are referred to as 'class G'. Class-G amplifiers can be based on class-AB or class-D circuits. The version based on class D is sometimes called class DG.

Fig.11 shows a version of the circuit in Fig.6 in which the supply is switched between two levels depending on the audio signal level. Again, this circuit is just for showing the basic concept and for producing illustrative waveforms – it is not a practical design. As before, the pulse rate is lower than in a typical real design to provide a clearer waveform drawing. The supply voltage switching is modelled using a pair of voltage-controlled voltage sources (`E1` and `E2`) with a table function to set the ranges of audio voltages to control the two supply levels. The triangle waveform amplitude is matched to the supply voltage using a behavioural source (`B1`) to multiply a 1V waveform by the supply voltage. The PWM waveform for a single cycle of the audio signal is shown in Fig.12.

Class-H amplifiers

Class-H amplifiers extend the concept of controlling the supply voltage by providing either a continuously variable or stepped supply voltage matched to the signal. Specifically, for signals above a certain level, the supply is set to a voltage just above the signal output level and sufficient for amplifier operation. Again, this can be applied to both class-AB and D amplifiers. Example waveforms for a class-D version are shown in Fig.13. The LTspice circuit in Fig.11 was adapted to produce this, with the continuously variable supply being modelled using two behavioural sources in place of the `E1` and `E2` table-based controlled sources. The behavioural source voltage was set using the equation `V=max(3,abs(V(audio))+1.4)`. The pulse frequency is a little higher than the previous examples to help emphasise the pulse amplitude shape, although the individual pulses are less clear.

The difference between class G and H can be confusing or inconsistent in different contexts, but often the distinguishing factor is that class G has two fixed supply rails and the amplifier switches between them, whereas class H has a single variable power supply. Thus class H is like driving the supply rail of one amplifier from another amplifier.

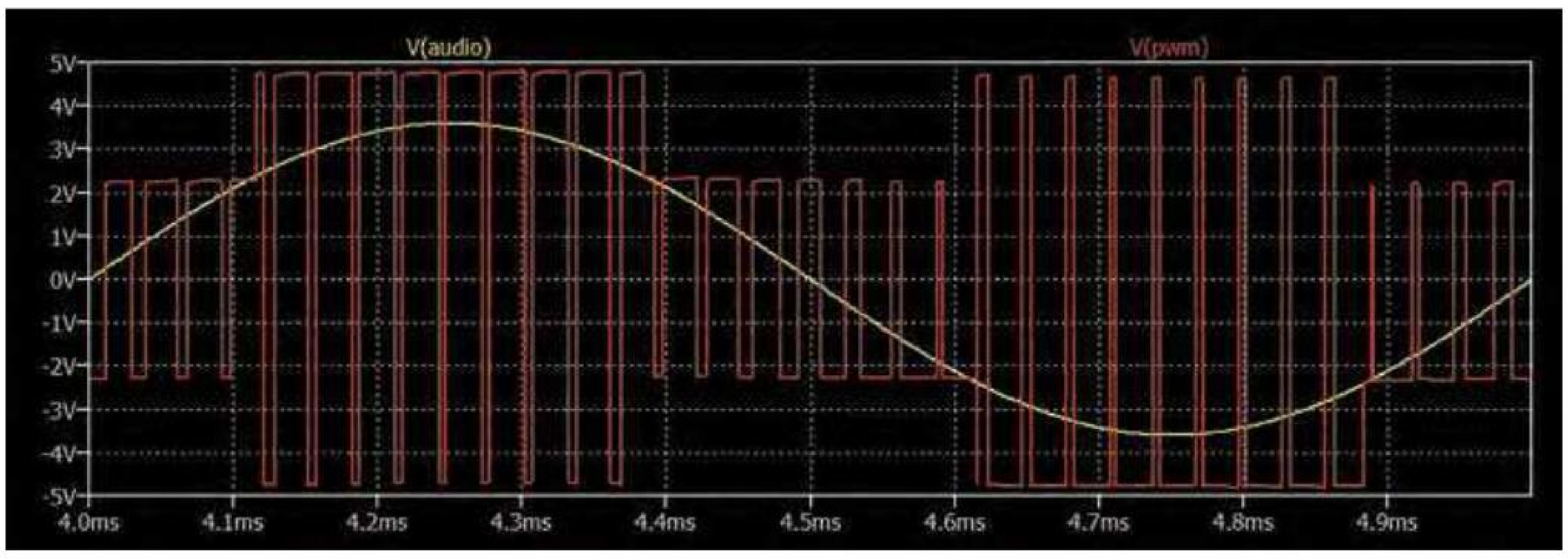


Fig.12. Amplifier waveforms from the circuit in Fig.11.

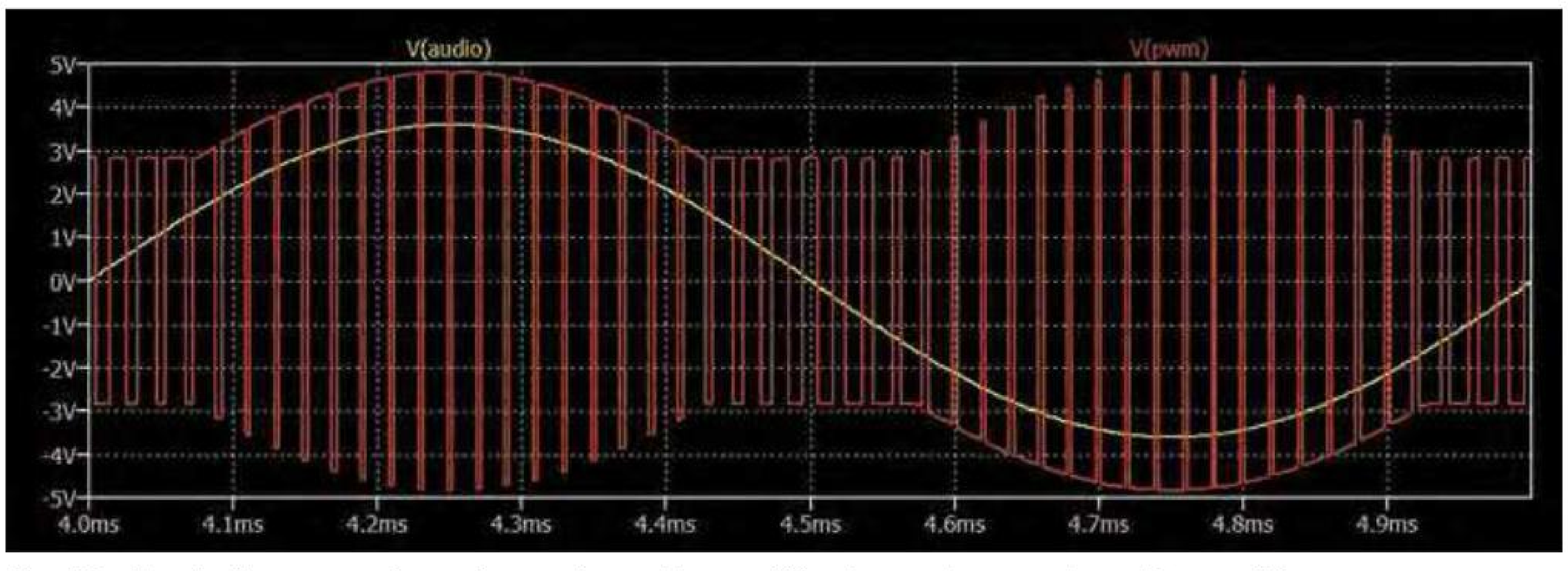


Fig.13. Illustrative waveform for a class-H amplifier based on a class-D amplifier.

Class-G and H ICs

Design of class-D amplifiers operating in class-G or H modes is far from trivial. Fortunately, some ICs are available which implement most of the functionality. For example, the MAX98307 from Maxim Integrated is a '3.3W, Mono Class DG Multilevel Speaker Amplifier' and the TAS2562 from Texas Instruments is '6.1W Boosted Class-D Audio Amplifier with IV Sense'. Both devices cost in the order of a pound or two for one-off (GBP, Mouser UK prices at the time of writing) and are aimed at applications such as mobile phones, tablet PCs, Bluetooth speakers and consumer audio devices. The MAX98307 has an audio input and is relatively straightforward. The TAS2562 (the subject of the article which prompted Julian to suggest this topic) is a more complex beast, with digital audio input at up to a 96kHz sample rate via I²S/TDM/I²C interfaces. It has a large number of control registers to customise device configuration (the datasheet runs to 114 pages). Texas Instruments provide software that can calculate register values and programme the device for development purposes.

The TAS2562 can operate in both class-G and class-H modes with the objective of extending battery life in portable/personal electronic devices with audio output. It uses an integrated DC-DC converter to produce the 'boost' supply voltage needed when higher output power is required. All class-G and H amplifiers require a means of measuring the signal and using this to adjust the supply ready for the signal level being amplified. This is relatively straightforward for the TAS2562 because it receives a stream of digital audio and holds multiple samples in its internal digital signal processing logic. Therefore, while a given sample is being applied to class-D modulator, the power supply control system can 'look ahead' at the later waveform samples to decide what to do with the supply voltage. The look ahead period can be in the range 1 to 20 samples, with something around 13 being typical at a 48kHz sample rate. This value is set by a control register.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

Practically Speaking

Hands-on techniques for turning ideas into projects – by Mike Hibbett

Introduction to surface-mount technology – Part 2

This month, we carry on from the previous *Practical Speaking* (April 2020) to take a closer look at SMDs (surface-mount devices), specifically how to select, purchase and use them. This month, we start with passive components; and in the next article we will cover the more complicated transistor and IC parts.

Resistance is futile!

There are many benefits to constructing circuits with SMD devices. Used predominantly in high-volume consumer electronic products, they are often cheaper than wire-ended equivalents, due simply to the scale of SMD use. By the same token, many interesting components are only available in surface-mount packages because they have been created for a specific high-volume application. Another benefit to hobbyists is that you do not need to drill holes in a circuit board to fit them, and as you do not need a hole passing through the PCB to mount them, you can get more components on a board – should you be adventurous enough to do double sided component placement. There is one major drawback however: size. SMD devices are small; sometimes absolutely tiny, so they pose challenges to hand soldering by the inexperienced. Let's take a look at some of the details, starting with the simplest of devices – resistors.

SMD resistors come in a range of packages. They are named after their dimensions, two digits for length and two for width, with those numbers being a multiple of 10 thousandths of an inch. For example, an 0805 package measures 0.08-inch × 0.05-inch. Fig.1 shows resistors in sizes 1206, 0805, 0603, 0402 and 0201. If you look carefully you may spot the 01005 part we pushed to one side (a rogue for breaking the package naming convention). For someone new to SMD soldering and with good eyesight 0805 packaged parts are a reasonable starting point; the author prefers to use 0603, as with time these become no harder to solder but do offer great space saving, which is important when you are trying to design small boards. The larger package sizes such as 1206 are only used when a larger power rating (1/4W) is useful. As the size decreases, so does the maximum working voltage, simply because the gap between the device's terminals reduces. An 0805 resistor is good to 150V, but an 0603 package is limited to 75V. This is rarely an issue for hobbyist projects but does need to be understood and remembered.

The resistors shown are all the same value and can perform identically in many applications. The key point to look out for when choosing a small component package is power rating; an 0805 resistor is typically rated for 1/8W, 0603 half that again. So be careful in power supply circuits or driving larger output loads with your choice of component sizes. If a resistor does not have sufficient power rating, put two resistors (of double the value) in parallel, or use a larger package (although there are benefits to standardising on a single size, as we will mention.) For typical hobbyist digital and audio projects these limits rarely come into play and will be highlighted by the project author or application note if they do.

Resistors come with their value printed on the part, at least in package sizes down to 0603. Below that size they all look the same – so storage and handling requires care. If you drop an SMD on the floor, our advice is to leave it and take another from the store. At less than half a penny each, the risk of picking up the wrong component is not worth it. Assuming you find it again, of course!

Component selection

Surface-mount components can be ordered from the usual online suppliers such as Farnell, RS Components and Digikey. Selecting a part can be challenging at first, so let's follow an example selection through, assuming you are looking for a 4.7kΩ resistor.

When choosing a traditional wire-ended resistor you would typically be facing just a few questions that can be easily answered – metal film, carbon or wire-wound? What power rating? What accuracy?

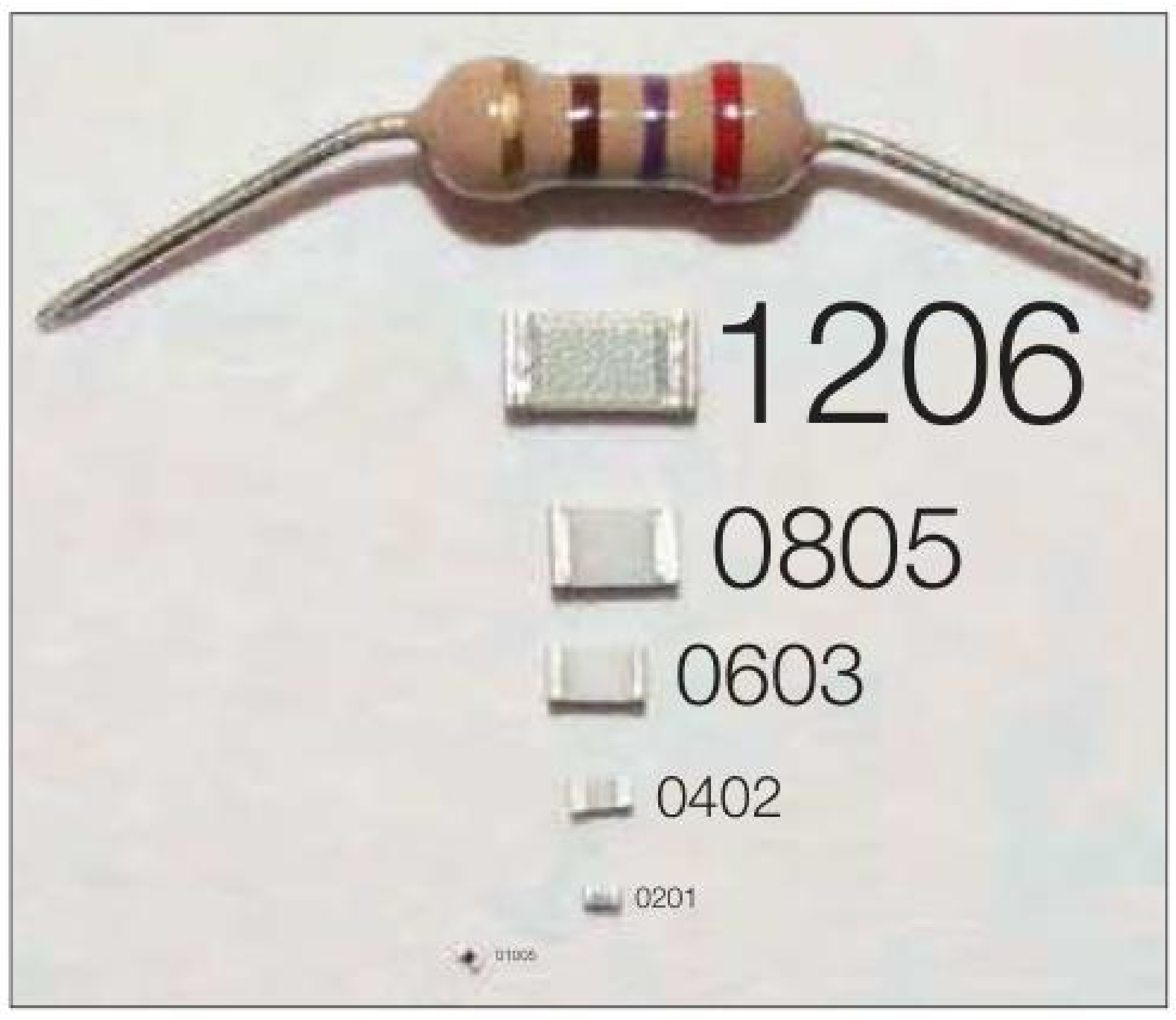
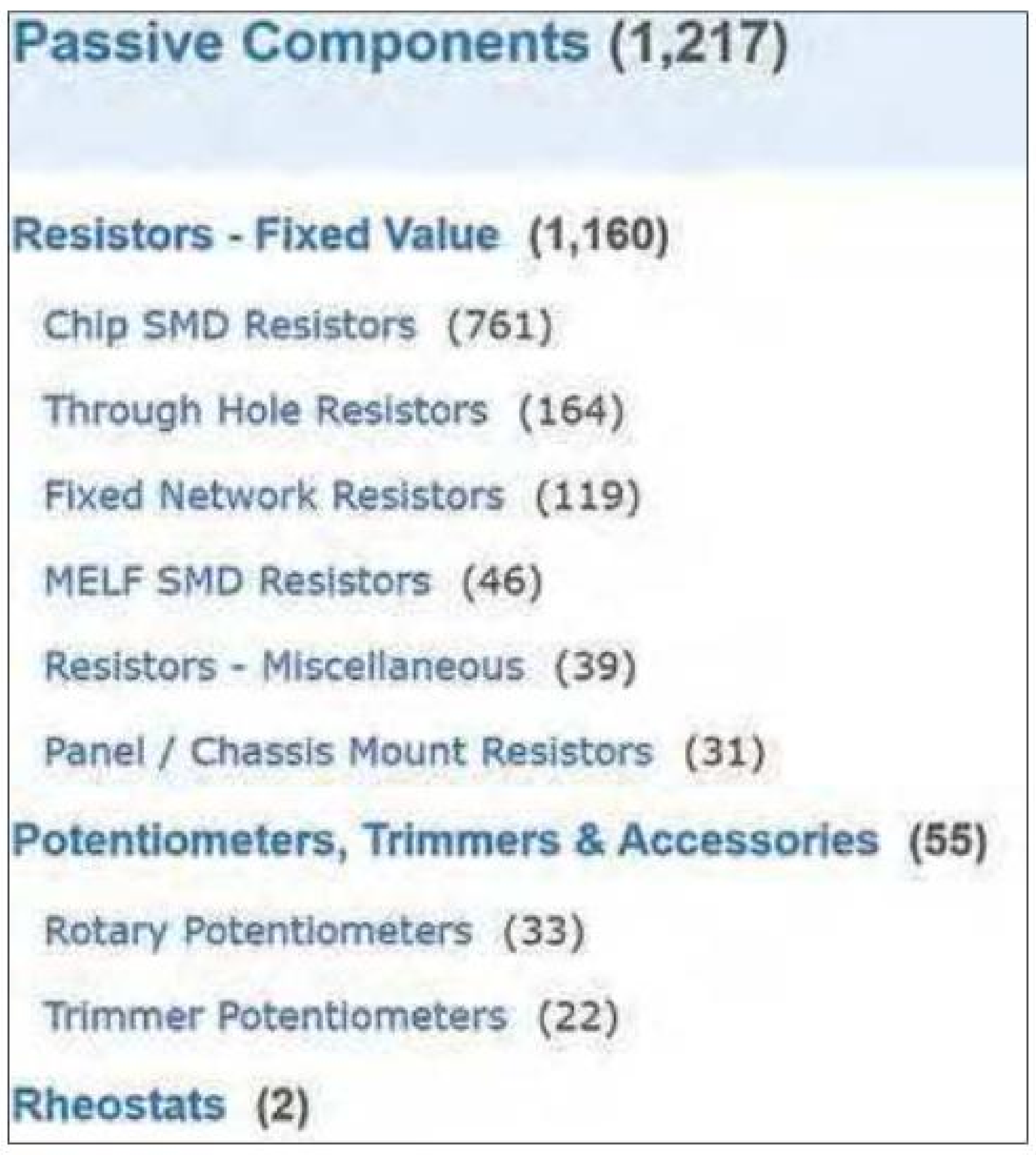


Fig.1. Various SMD resistor sizes, compared to a 1/4W wire-ended part – the smallest 'dot' is a 01005 device.

The selection criteria for surface-mount components is broader than with traditional wire-ended components; visiting the Farnell website and entering '4K7' in the search bar yielded 161 options for through-hole resistors, and over 800 options for SMD, as shown in Fig.2.

Where do you start?!

When you click on 'Chip SMD Resistors', a set of filters appear (thankfully!) as shown in Fig.3. From here, you can further refine your search. Before we do, let's take a moment to analyse the list. We are showing eight of the ten filters shown on the actual website. The voltage rating is something we rarely think about with-wire ended resistors; some of these parts are limited to just 15V. This



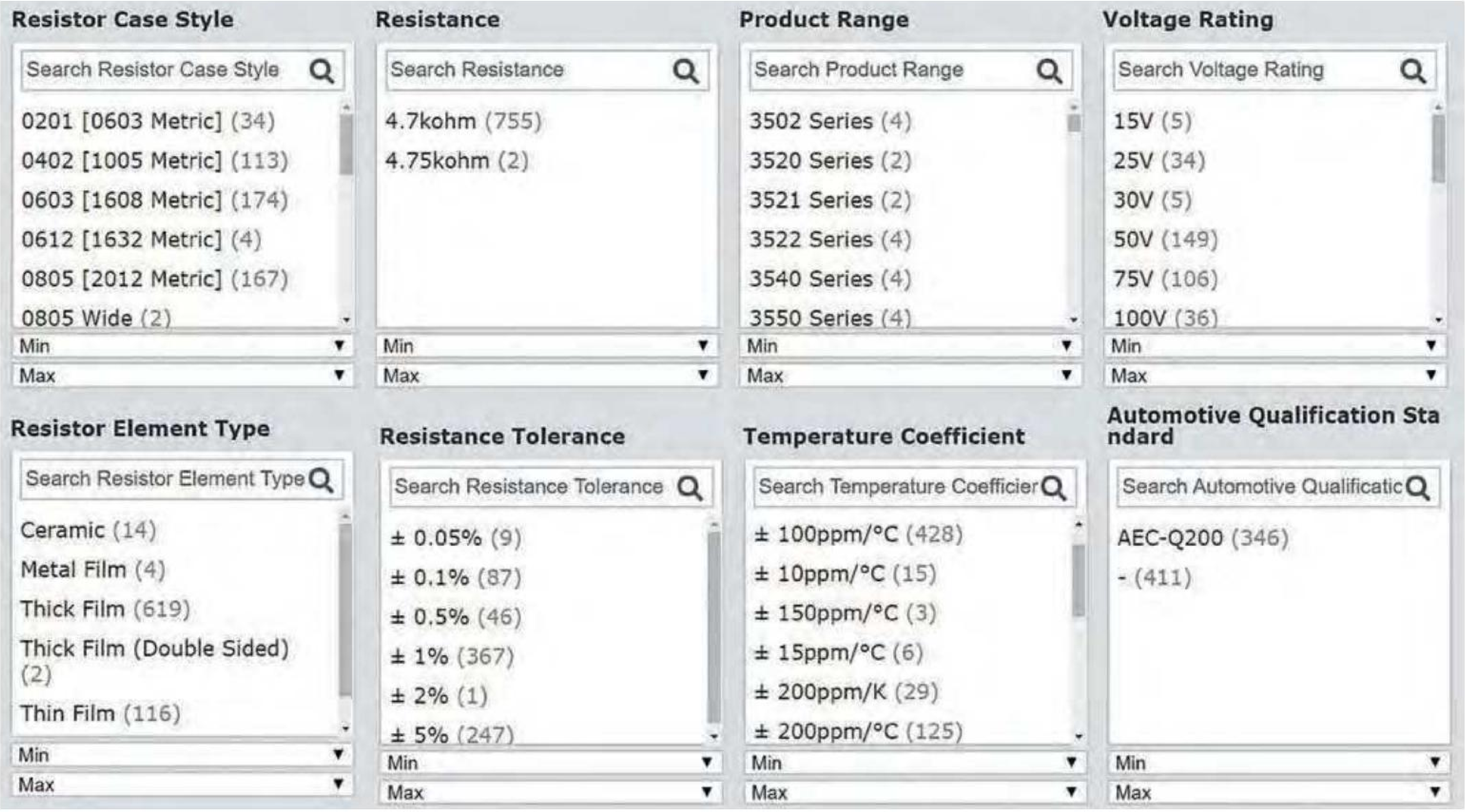
Passive Components (1,217)

Resistors - Fixed Value (1,160)
- Chip SMD Resistors (761)
- Through Hole Resistors (164)
- Fixed Network Resistors (119)
- MELF SMD Resistors (46)
- Resistors - Miscellaneous (39)
- Panel / Chassis Mount Resistors (31)

Potentiometers, Trimmers & Accessories (55)
- Rotary Potentiometers (33)
- Trimmer Potentiometers (22)

Rheostats (2)

Fig.2. 4K7 (4.7kΩ) resistors available on the Farnell website: 1217 different types!



Resistor Case Style

Search Resistor Case Style

- 0201 [0603 Metric] (34)
- 0402 [1005 Metric] (113)
- 0603 [1608 Metric] (174)
- 0612 [1632 Metric] (4)
- 0805 [2012 Metric] (167)
- 0805 Wide (2)

Min ▼
Max ▼

Resistance

Search Resistance

- 4.7kohm (755)
- 4.75kohm (2)

Min ▼
Max ▼

Product Range

Search Product Range

- 3502 Series (4)
- 3520 Series (2)
- 3521 Series (2)
- 3522 Series (4)
- 3540 Series (4)
- 3550 Series (4)

Min ▼
Max ▼

Voltage Rating

Search Voltage Rating

- 15V (5)
- 25V (34)
- 30V (5)
- 50V (149)
- 75V (106)
- 100V (36)

Min ▼
Max ▼

Resistor Element Type

Search Resistor Element Type

- Ceramic (14)
- Metal Film (4)
- Thick Film (619)
- Thick Film (Double Sided) (2)
- Thin Film (116)

Min ▼
Max ▼

Resistance Tolerance

Search Resistance Tolerance

- ± 0.05% (9)
- ± 0.1% (87)
- ± 0.5% (46)
- ± 1% (367)
- ± 2% (1)
- ± 5% (247)

Min ▼
Max ▼

Temperature Coefficient

Search Temperature Coefficier

- ± 100ppm/°C (428)
- ± 10ppm/°C (15)
- ± 150ppm/°C (3)
- ± 15ppm/°C (6)
- ± 200ppm/K (29)
- ± 200ppm/°C (125)

Min ▼
Max ▼

Automotive Qualification Standard

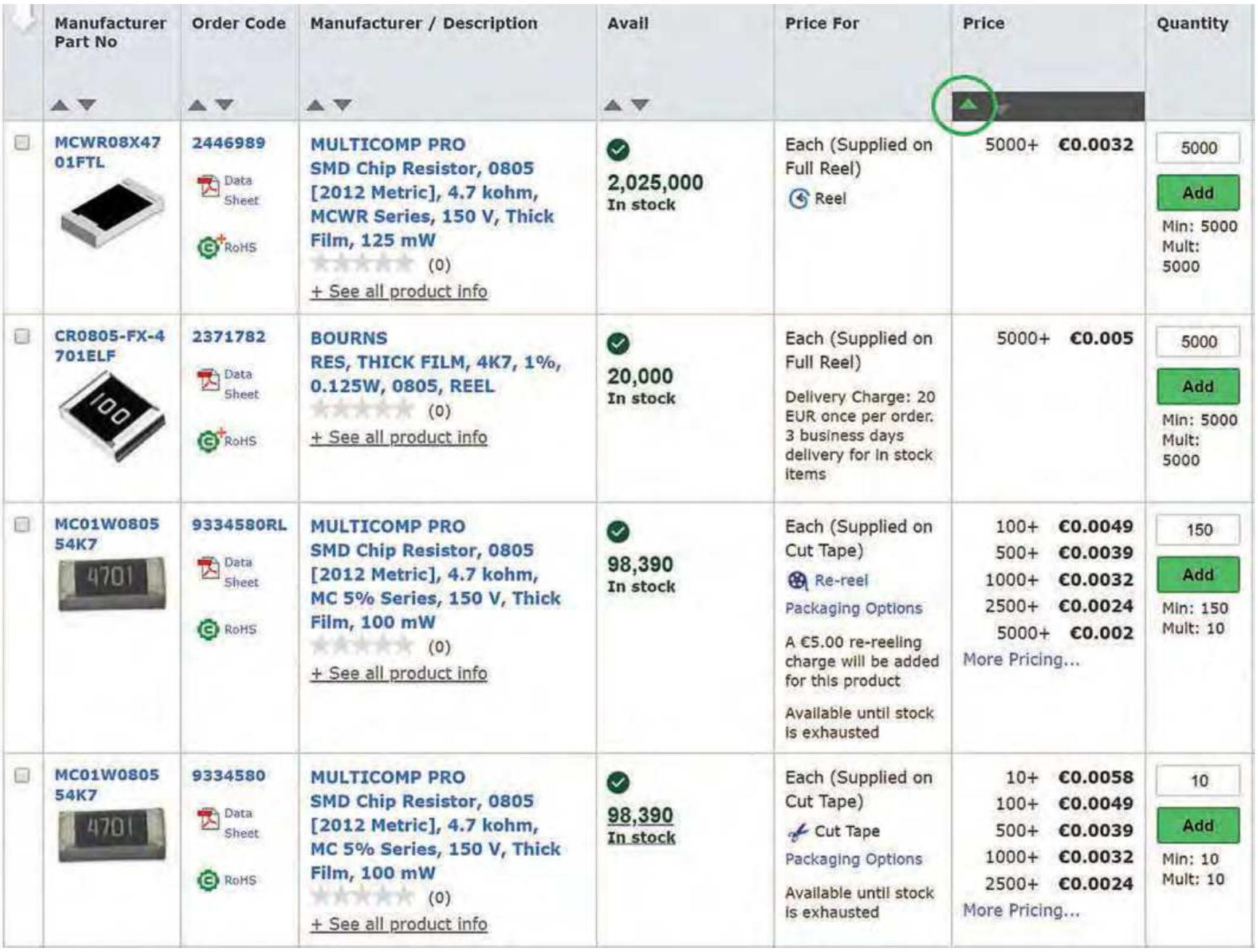
Search Automotive Qualificatic

- AEC-Q200 (346)
- - (411)

Min ▼
Max ▼

Fig.3. Component selection filter options on the Farnell website.

is a consequence of the size reduction. Thankfully, most of the parts are rated at 50V and above, and so are suitable for most hobbyist designs. The ‘Resistor Element Type’ refers to how the resistance of the part is created, and it’s no surprise that ‘Thick Film’ is the most popular, as it is the main technology outside of specialised resistors with very high accuracy



	Manufacturer Part No	Order Code	Manufacturer / Description	Avail	Price For	Price	Quantity
☐	MCWR08X4701FTL	2446989 Data Sheet RoHS	MULTICOMP PRO SMD Chip Resistor, 0805 [2012 Metric], 4.7 kohm, MCWR Series, 150 V, Thick Film, 125 mW (0) + See all product info	2,025,000 In stock	Each (Supplied on Full Reel) Reel	5000+ €0.0032	5000 Add Min: 5000 Mult: 5000
☐	CR0805-FX-4701ELF	2371782 Data Sheet RoHS	BOURNS RES, THICK FILM, 4K7, 1%, 0.125W, 0805, REEL (0) + See all product info	20,000 In stock	Each (Supplied on Full Reel) Delivery Charge: 20 EUR once per order. 3 business days delivery for in stock items	5000+ €0.005	5000 Add Min: 5000 Mult: 5000
☐	MC01W080554K7	9334580RL Data Sheet RoHS	MULTICOMP PRO SMD Chip Resistor, 0805 [2012 Metric], 4.7 kohm, MC 5% Series, 150 V, Thick Film, 100 mW (0) + See all product info	98,390 In stock	Each (Supplied on Cut Tape) Re-reel Packaging Options A €5.00 re-reeling charge will be added for this product Available until stock is exhausted	100+ €0.0049 500+ €0.0039 1000+ €0.0032 2500+ €0.0024 5000+ €0.002 More Pricing...	150 Add Min: 150 Mult: 10
☐	MC01W080554K7	9334580 Data Sheet RoHS	MULTICOMP PRO SMD Chip Resistor, 0805 [2012 Metric], 4.7 kohm, MC 5% Series, 150 V, Thick Film, 100 mW (0) + See all product info	98,390 In stock	Each (Supplied on Cut Tape) Cut Tape Packaging Options Available until stock is exhausted	10+ €0.0058 100+ €0.0049 500+ €0.0039 1000+ €0.0032 2500+ €0.0024 More Pricing...	10 Add Min: 10 Mult: 10

Fig.4. Typical list of resistors on the Farnell website.

or temperature stability. The resistor tolerance is something we can largely ignore; unless specifically required, 5% tolerance (E24 series) will be fine.

Finally, we have the key parameter 'Resistor Case Style'. There is a blistering array of choice here; the scroll box shown in Fig.3 has 19 options. The selection here is easy – choose your favourite size. A good starter size is 0805, but when you get more comfortable with SMDs you will probably move down to 0603. Note that when we say '0603' we are referring to the imperial measurement, not the metric size. PCB design is one of those rare professions where it is common to mix measurement units. PCB dimensions and hole sizes are often quoted in metric, while track widths, pin spacing and component sizes are quoted in Imperial. Be careful when reading datasheet dimensions that you know whether a value is in thou (aka 'mil') or mm!

When we click on 'Apply Filters' we get to see the list of potential purchases – a choice of 123 different parts matching our specification. This may be daunting at first, but there is a simple trick – click on the icon shown in Fig.4. to sort by increasing price, and pick the cheapest – there is really no reason to be more selective than that with general purpose resistors.

This filter will show the minimum priced device first, but does not filter on minimum quantity – so to pay 0.0032 Euro for a resistor, you will have to buy 5000 of them. You may laugh at that, but remember this is only 15 Euro for a lifetime supply of 4.7kΩ resistors! You have to scroll down a little to find the price for parts offered in more sensible quantities – at a minimum order quantity of 10 parts, you will pay half a Euro Cent each. Do pay attention to the 'Price For' column, as it indicates how the part will be supplied – on a reel or cut tape. You can see the two bulk packaging options in Fig.5. A reel is simply a reel of tape, so the components are basically shipped in the same format. This only becomes important if you are buying components to send to a PCB assembly house – they will need the components on a reel.

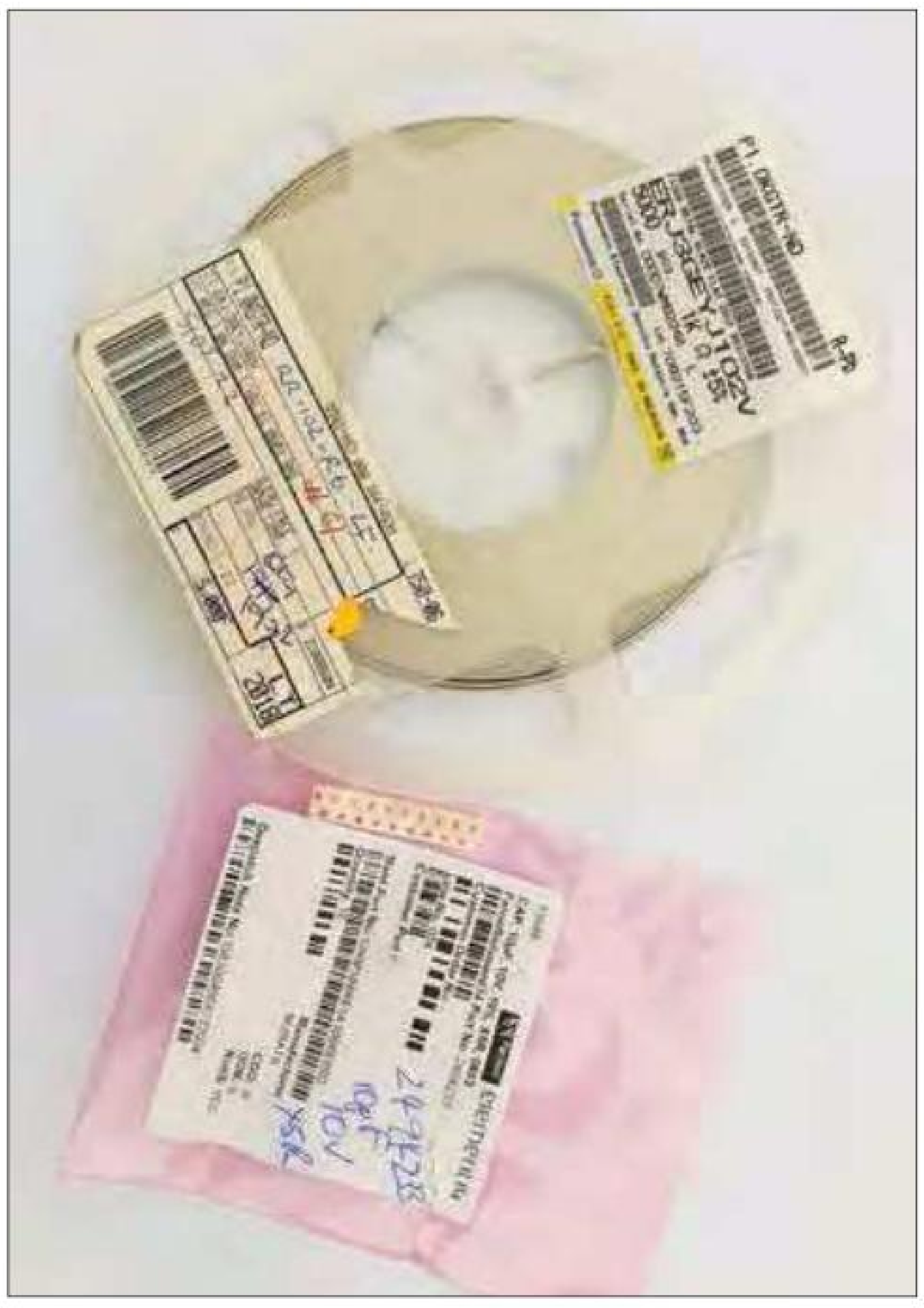


Fig.5. Examples of components on reel and cut tape.

SMD capacitors

Now let's take a look at capacitors, where the story gets slightly more complicated. At values above 1µF, you need to pay close attention to the working voltage of the part. For any value of capacitance, you need to pay attention to the 'series' of the capacitor (commonly stated in selection parameters as CoG or X5R) which really refers to its stability across temperature range and working voltage. (This is not a parameter specific to SMD devices, however – the series rules apply equally to wire-ended devices).

Where the choice of an SMD capacitor does get interesting is in the use of higher value capacitors. Many of us are used to working with leaded electrolytic or tantalum capacitors, but when choosing SMD components, ceramic capacitors are often the first point of call. Ceramic capacitors are easy to use because they are not polarised, but do be aware that they get more expensive as the value increases above 10µF. They are, however, our capacitor of choice because the parts remain small and have long storage and operational life.

Ceramic capacitors have no value marking, even in the larger SMD sizes. However, high-value tantalum capacitors are marked, The lack of marking on ceramic capacitors is due to the material they are constructed from not taking well to the printing process (ie, it would be too expensive to do it effectively with a bespoke printing process.)

Buying components

With SMD components being so cheap, it's rare to buy a single component when you need one. Typically, the minimum quantity is 10, so it's very easy to build up an unorganised collection of SMD parts in your component 'stock'.

There are two approaches to this. First, standardise on a particular size of component as your 'default' size. Having done that, buy a reel of some of the common values. For resistors, a 5000-part reel of a given value can be bought on eBay for less than £5; it's worth the wait for a lifetime supply.

Second, it's possible to buy a complete set of 'all values' of a component in a book format. This consists of perhaps 20 – 50 parts of each and every value in the E24 range – over 4000 individual components – all in a specific package size. The author has three books of resistors in 0805, 0604 and 0402 package sizes. Each book measures 8 × 6 × 1 inches in size, so it's very compact. For example, at the time of writing, eBay item 291874912665 with 4250 pieces at £15.99 including delivery.

Books of components save lots of space, are easy to use and offer excellent value for money. For around £15 you get over 4600 resistors – at a cost of under 1/3 of a penny each. The components are supplied in tape form and slot into the book, so when you run out of a strip they can be replaced easily by purchasing through a normal distributor like Farnell. Even the plastic pages can be replaced.

Books of capacitors follow the same approach but are approximately twice the price, which is to be expected as large value capacitors are expensive. We find our component books invaluable, and a terrific space saver in the lab. It won't stop you needing to purchase the occasional exotic part, but you will be buying things less frequently – and avoiding extra shipping costs.

PCB design

Using surface-mount components implies you are using a PCB, either home-made or purchased from one of the low-cost Far-east suppliers. This means that you will be using a PCB design tool, which brings up its own set of challenges. With surface-mount components it is essential that you select the correct footprint – the area of exposed copper on the PCB – when laying out the PCB. Leaded components can be 'adjusted' to fit incorrect pads; SMDs have no such capability. Resistors and capacitors follow relatively simple footprint standards but ICs, connectors and other solderable parts come with varying or non-standard footprints. If you have the components to hand in advance of designing the PCB, print the board out at a 1:1 scale on paper and verify the components fit. We've been caught out on more than one project with incorrect-width IC packages.

With all SMD component footprints, ensure that the pads are a little longer than the component placed on it; compact solder pads are great for professional soldering machines and help free up board space, but remember that you will be soldering these components by hand with an iron.

When laying out the PCB design, it's tempting to bring components close together – that may be why you chose SMD components in the first place. When placing components close to other parts at the design stage, be mindful of how you will actually solder them down. Take Fig.6

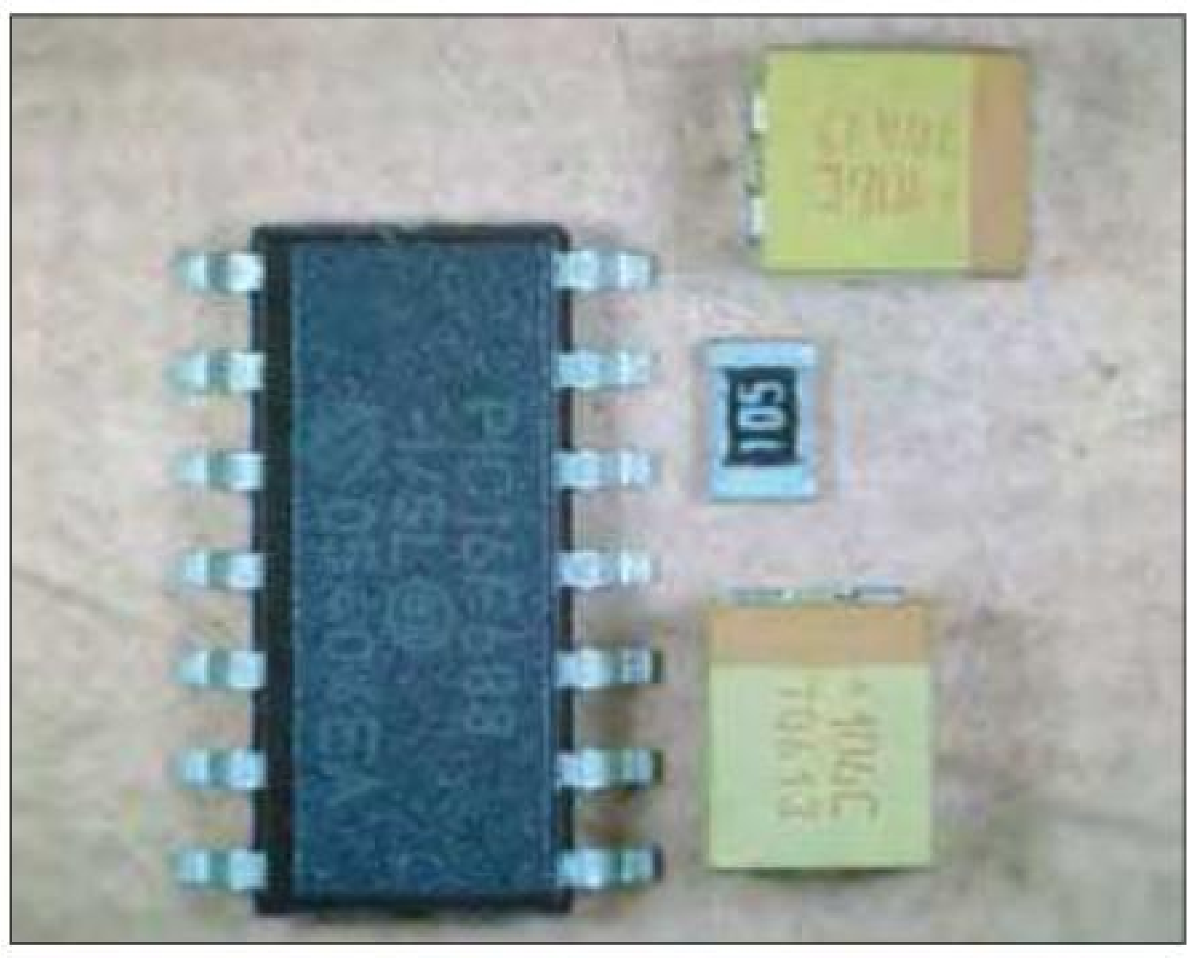


Fig.6. A potentially troublesome SMD component layout – soldering order matters!

for example; It would be very challenging to solder the IC or resistor if the capacitors had been placed down first – you would have difficulty getting the soldering iron into the small pads. A PCB laid out like this requires that the IC be soldered first, followed by the resistor and only then the two capacitors.

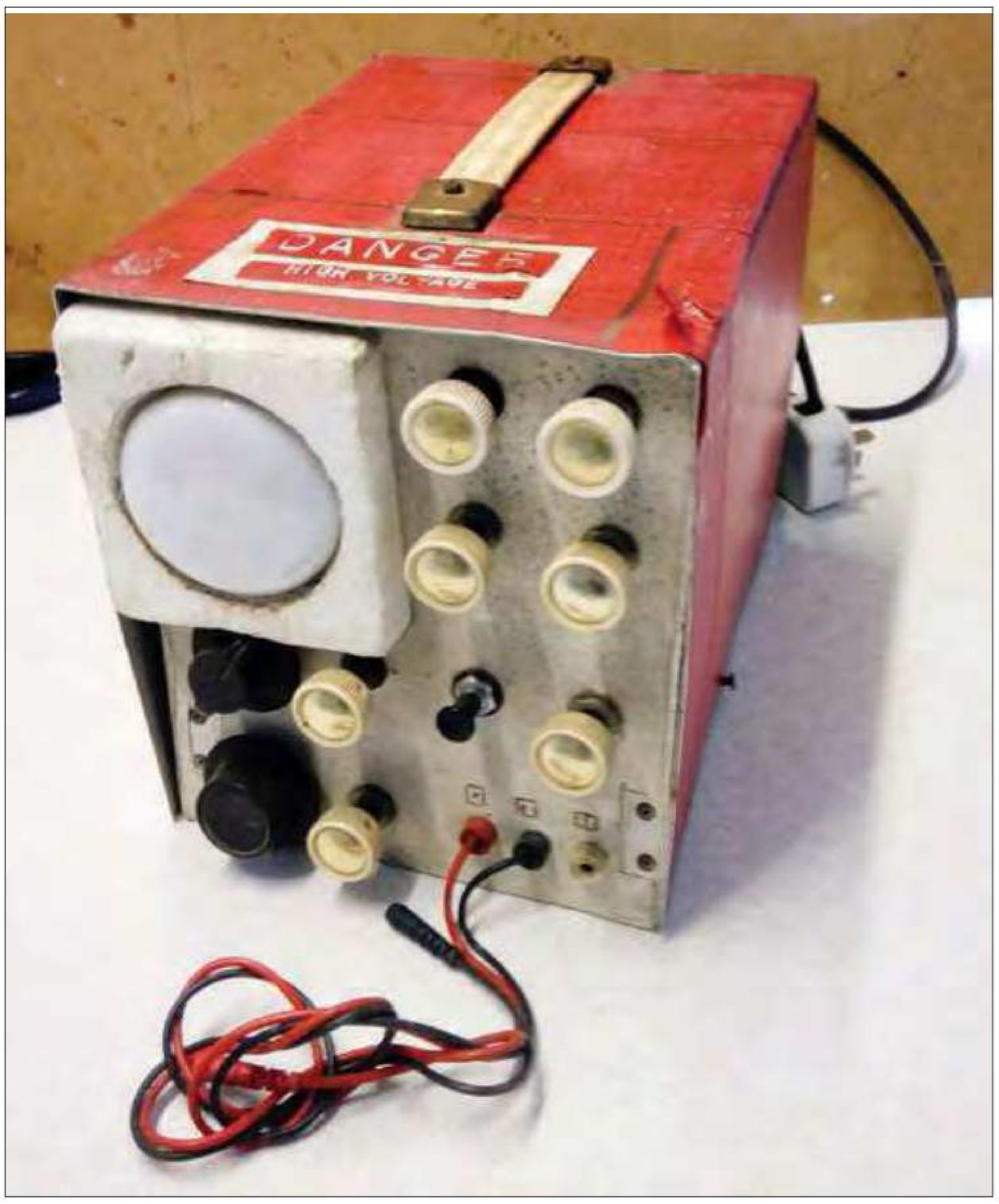
Next up

In our concluding article in the next *Practically Speaking* column we will move onto the more complex task of IC and transistor selection.

Blast from the past

Our previous *Practically Speaking* column caught the eye of one reader – the article included a photograph of the cover of the March 1965 issue of *Practical Electronics*. That cover showed a 'build it yourself' oscilloscope project. Reader David Hannaford reached out to say he built that scope in 1965, and still has it. He kindly sent us a photograph.

David Hannaford wrote: 'Mike – Love your articles in *PE* and especially your reference in the latest magazine to the 1965 *PE Oscilloscope* that I built at that time as my first big *PE* project. I still have it [see photo above] but not sure about running it now as 55-year-old capacitors and 600V floating around sounds a bit dangerous.'



Many thanks for the feedback and photo David, I have a soft spot for that issue of the magazine as it was the month I was born. I'm glad to report I am still running!

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LAMBDA GENESYS	PSU GEN50-30 50V 30A	£400
IFR 2025	Signal Generator 9kHz – 2.51GHz Opt 04/11	£900
IFR 2948B	Communication Service Monitor Opts 03/25 Avionics	POA
IFR 6843	Microwave Systems Analyser 10MHz – 20GHz	POA
R&S APN62	Syn Function Generator 1Hz – 260kHz	£295
Agilent 8712ET	RF Network Analyser 300kHz – 1300MHz	POA
HP8903A/B	Audio Analyser	£750 – £950
HP8757D	Scaler Network Analyser	POA
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£400
HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHz – 20GHz	£2,000
HP83630A	Synthesised Sweeper 10MHz – 26.5 GHz	POA
HP83624A	Synthesised Sweeper 2 – 20GHz	POA
HP8484A	Power Sensor 0.01-18GHz 3nW-10µW	£75
HP8560E	Spectrum Analyser Synthesised 30Hz – 2.9GHz	£1,750
HP8563A	Spectrum Analyser Synthesised 9kHz – 22GHz	£2,250
HP8566B	Spectrum Analsyer 100Hz – 22GHz	£1,200
HP8662A	RF Generator 10kHz – 1280MHz	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325
Marconi 2024	Synthesised Signal Generator 9kHz – 2.4GHz	£800
Marconi 2030	Synthesised Signal Generator 10kHz – 1.35GHz	£750
Marconi 2023A	Signal Generator 9kHz – 1.2GHz	£700
Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHz	£295
Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 2955B	Radio Communications Test Set	£800
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHz – 20GHz	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B	Power Meter with 6910 sensor	£295
Tektronix TDS3052B	Oscilloscope 500MHz 2.5GS/s	£1,250
Tektronix TDS3032	Oscilloscope 300MHz 2.5GS/s	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHz 1.25GS/s	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHz 100MS/s	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHz	£600
Farnell AP60/50	PSU 0-60V 0-50A 1kW Switch Mode	£300
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell AP100-90	Power Supply 100V 90A	£900
Farnell LF1	Sine/Sq Oscillator 10Hz – 1MHz	£45
Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
Racal 9300B	As 9300	£75
Solartron 7150/PLUS	6½ Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHz – 20kHz	£600
Solartron SI 1255	HF Frequency Response Analyser	POA
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160 – £200
Thurlby TG210	Function Generator 0.002-2MHz TTL etc Kenwood Badged	£65
HP33120A	Function Generator 100 microHz – 15MHz	£350
HP53131A	Universal Counter 3GHz Boxed unused	£600
HP53131A	Universal Counter 225MHz	£350
Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

HP/Agilent HP 34401A Digital
Multimeter 6½ Digit £325 – £375

Marconi 2955B Radio
Communications Test Set – £800

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 17: Building the Micromite Robot Buggy

In last month's article, we introduced you to the new *Micromite Robot Buggy (MRB)*. This month, we will work through the assembly process resulting in the *MRB* shown to the right.

Please note that references this month to Fig.17 and below mean photos and diagrams from last month, hence you will need to have a copy of *Part 16* (*PE*, May 2020) to hand.

Circuit diagram

Fig.18 shows the *MRB's* circuit diagram, and as with most *MIWM* modules in this series, the circuit is relatively straightforward. It is just a matter of connecting three modules (MOD1-MOD3), and two components (S1, R1), to the correct Micromite pins. There are three distinct parts to the schematic: the motor circuit, the power circuit, and the connectors for attaching existing *MIWM* hardware modules. Let's take each of these in turn.

Motor circuit

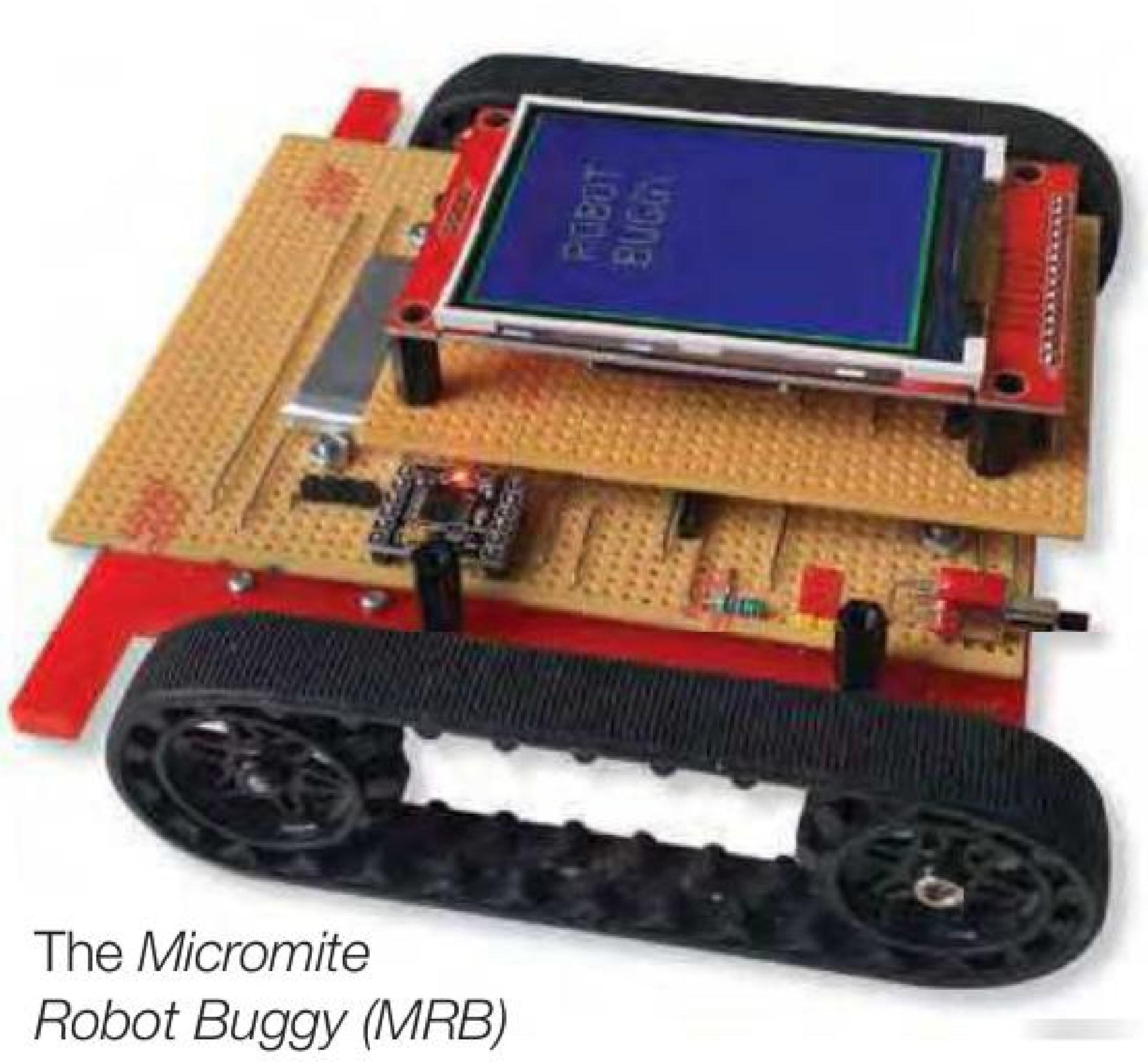
The motor circuit comprises a motor driver module (MOD1), and the two DC motors (M1, M2). The motor driver module simply boosts/'amplifies' four signals (two for each motor) from the Micromite. Each Micromite output pin can only supply a maximum current of circa 20mA and hence the motor module 'amplifies' this to what the motors require; the exact figure depends on the motor type (and gear ratio) used, and also the weight of the robot. Two *MKC* pins control one motor, and two more *MKC* pins control the other motor. A PWM signal is used on one side of each motor to control its speed, and this is why pins 4 and 5 have been used (PWM 1A and 1B). Standard I/O pins can be used to drive the other contact on each motor – here we have used pins 9 and 10.

Power circuit

The power circuit is greatly simplified thanks to the LiPo Charger/Booster module (MOD3). When a 3.7V LiPo battery is plugged into this booster module, there will be an output of approximately 5.2V on the 5V pin (assuming the battery has some charge in it!). Pulling MOD3's EN pin low (0V) turns off the MOD3 5V ouput. The EN

Micromite code

The code in this article is available for download from the *PE* website.


The *Micromite* *Robot Buggy (MRB)*

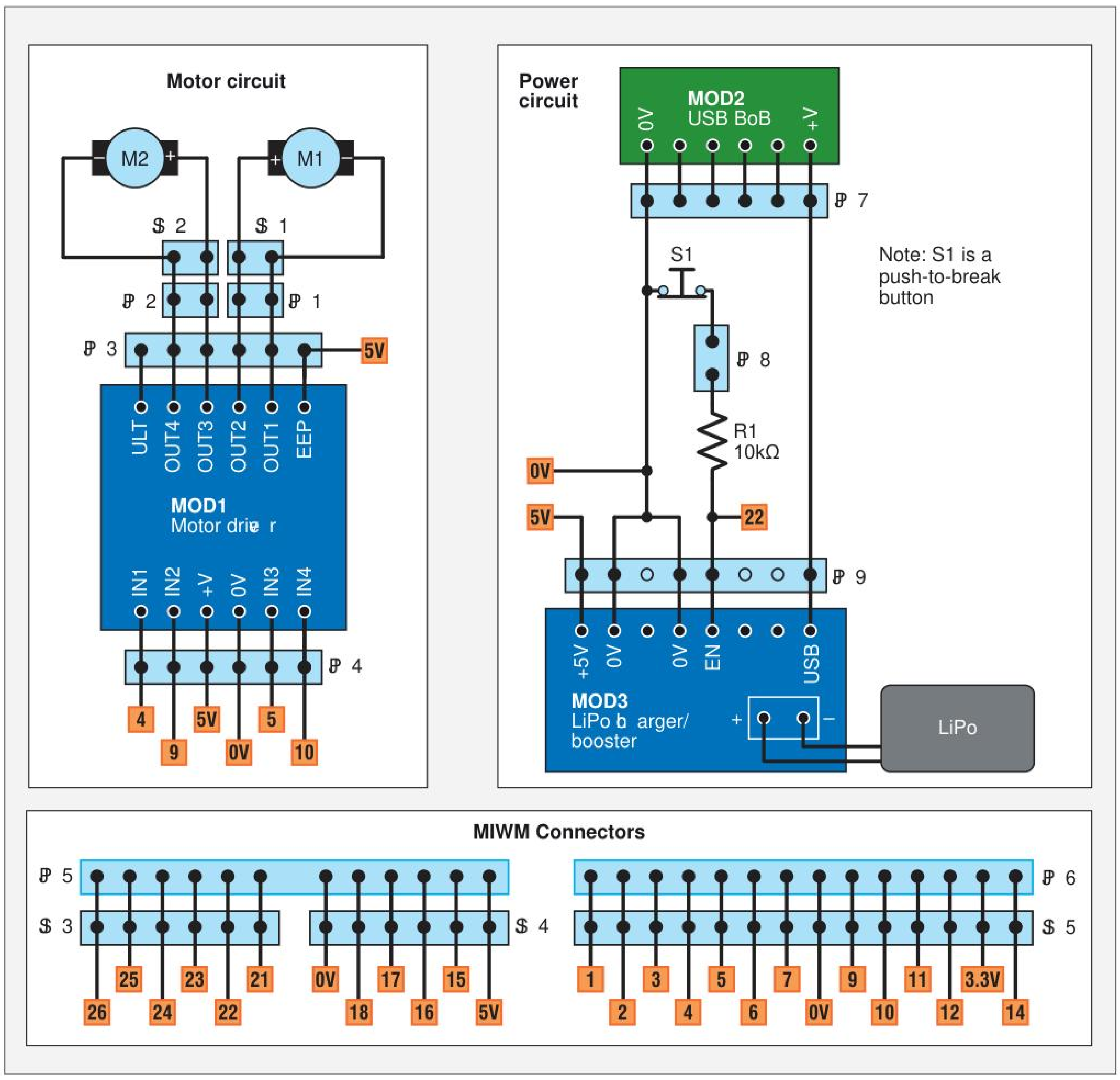

Motor circuit
M2
M1
$ 2
$ 1
Ᵽ 2
Ᵽ 1
Ᵽ 3
5V
ULT
OUT4
OUT3
OUT2
OUT1
EEP
MOD1
Motor driver
IN1
IN2
+V
0V
IN3
IN4
Ᵽ 4
4
9
5V
0V
5
10
Power circuit
MOD2
USB BoB
0V
+V
Ᵽ 7
S1
Note: S1 is a push-to-break button
Ᵽ 8
R1
10kΩ
0V
5V
22
Ᵽ 9
+5V
0V
0V
EN
USB
MOD3
LiPo charger/
booster
LiPo
MIWM Connectors
Ᵽ 5
$ 3
25
23
21
26
24
22
0V
17
15
18
16
5V
$ 4
Ᵽ 6
$ 5
1
3
5
7
9
11
3.3V
2
4
6
0V
10
12
14

Fig.18. Circuit diagram for the *MRB*. There are three distinct parts: motor circuit, power circuit and connectors for *MIWM* hardware.

pin is tied to +V via an *internal* 200kΩ pull-up resistor. You can see in Fig.18 that the EN pin is also connected to 0V via R1 (10kΩ), jumper-link (JP8), and a push-to-break button (S1). With the jumper link in place (ignore pin 22 for now), the 5.0V output is off because the potential divider formed by 10kΩ and 200kΩ means EN is still effectively pulled low to nearly 0V. If the jumper link is removed, the EN pin is pulled high by the module's internal 200kΩ resistor, and the 5V output will turn on. Refitting the jumper link will turn off the 5V output once again (for the aforementioned reasons).

Now consider button (S1). When pressed, the 5V output will be on, and when released, the output will be off.

Next we turn to the pin 22 connection. When S1 is pressed, the 5V output turns on (and the *MKC* powers up). If our program sets pin 22 high at the start of the code, then when S1 is released, the 5V output will not switch off because the EN pin is being held high via pin 22.

So how do we now turn off the power other than disconnecting the battery? The answer is to simply set pin 22 low. This is just a nice little trick to allow the robot to be turned off with a touch-screen or infrared remote control. Turning the robot on will always require S1 to be pressed (or the jumper link to be removed).

When it comes to charging the LiPo battery, the USB pin on the LiPo Charger/Booster module needs to be fed with a 5V power source (with a capacity of at least 1A).

MOD2, the USB breakout board (BoB) is used as a socket to supply 5V charging power to MOD3 USB pin. MOD2 is mounted at the back of the robot, providing a convenient place to attach a 5V supply to recharge the robot's battery. We recommend using a phone charger for this function, or alternatively a RaspberryPi PSU (these have a micro-USB connector and can comfortably supply at least 2A).

MIWM Connectors

The connectors need to be positioned correctly (as shown in Fig.21) to allow connection to other *MIWM* hardware modules. They pass the *MKC* signals to the daughterboard, and also to any other *MIWM* module that is plugged in. They do not affect the circuit in any other way.

Pin mappings

Before we go into specific assembly details, it is first worth having a quick look at how the 19 available Micromite I/O pins are being used in the *MRB* – see Table 2. You can see that most pins have been assigned already; however, there are still four available for future use.

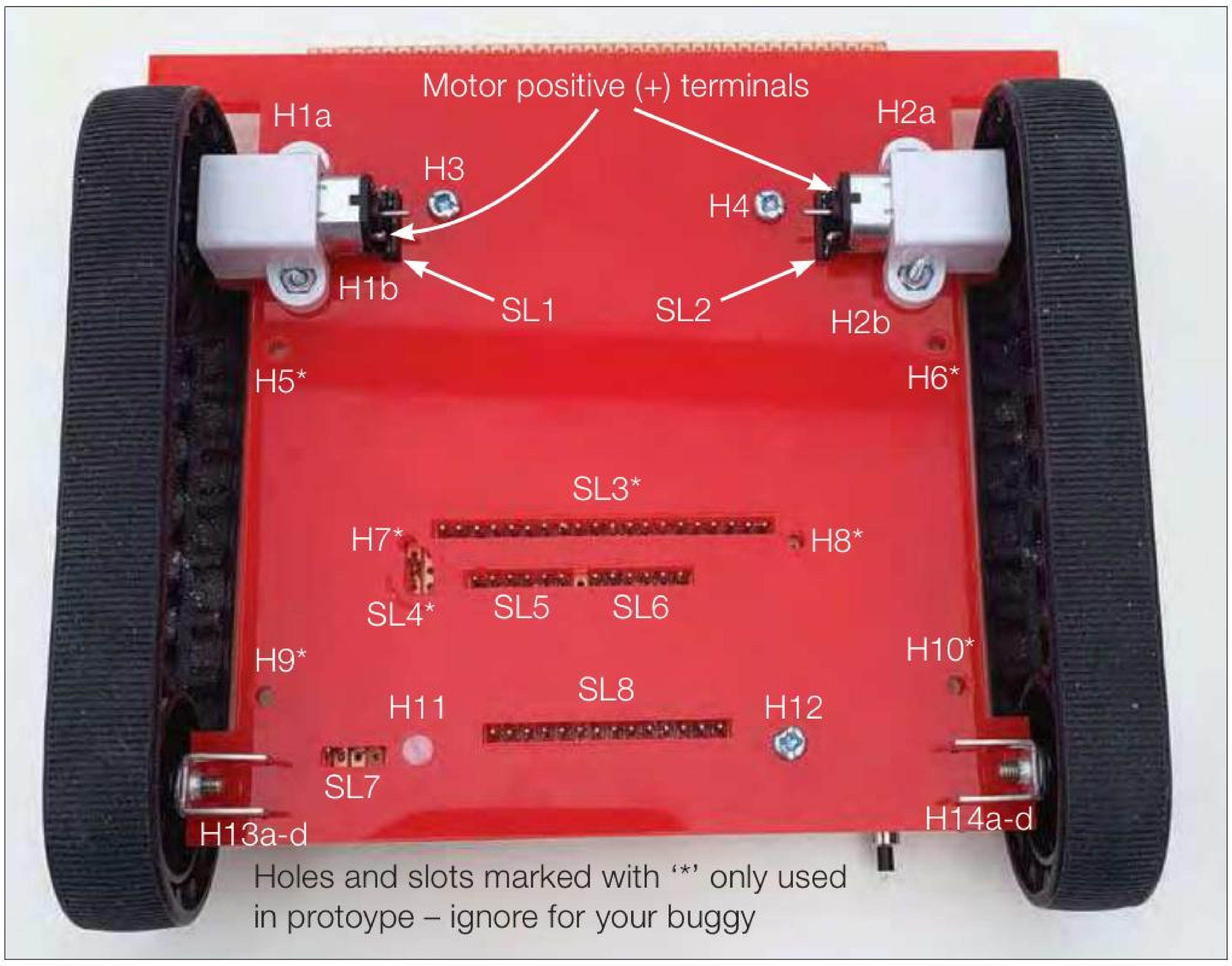

Motor positive (+) terminals
H1a
H2a
H3
H4
H1b
SL1
SL2
H2b
H5*
H6*
SL3*
H7*
H8*
SL4*
SL5
SL6
H9*
H10*
H11
SL8
H12
SL7
H13a-d
H14a-d
Holes and slots marked with '*' only used in protoyype – ignore for your buggy

Fig.19. The underside of the buggy showing slot (SL*x*) and hole (H*x*) references. As shown, the *MKC* and Bluetooth module have yet to be attached.

Guide to assembling the MRB chassis

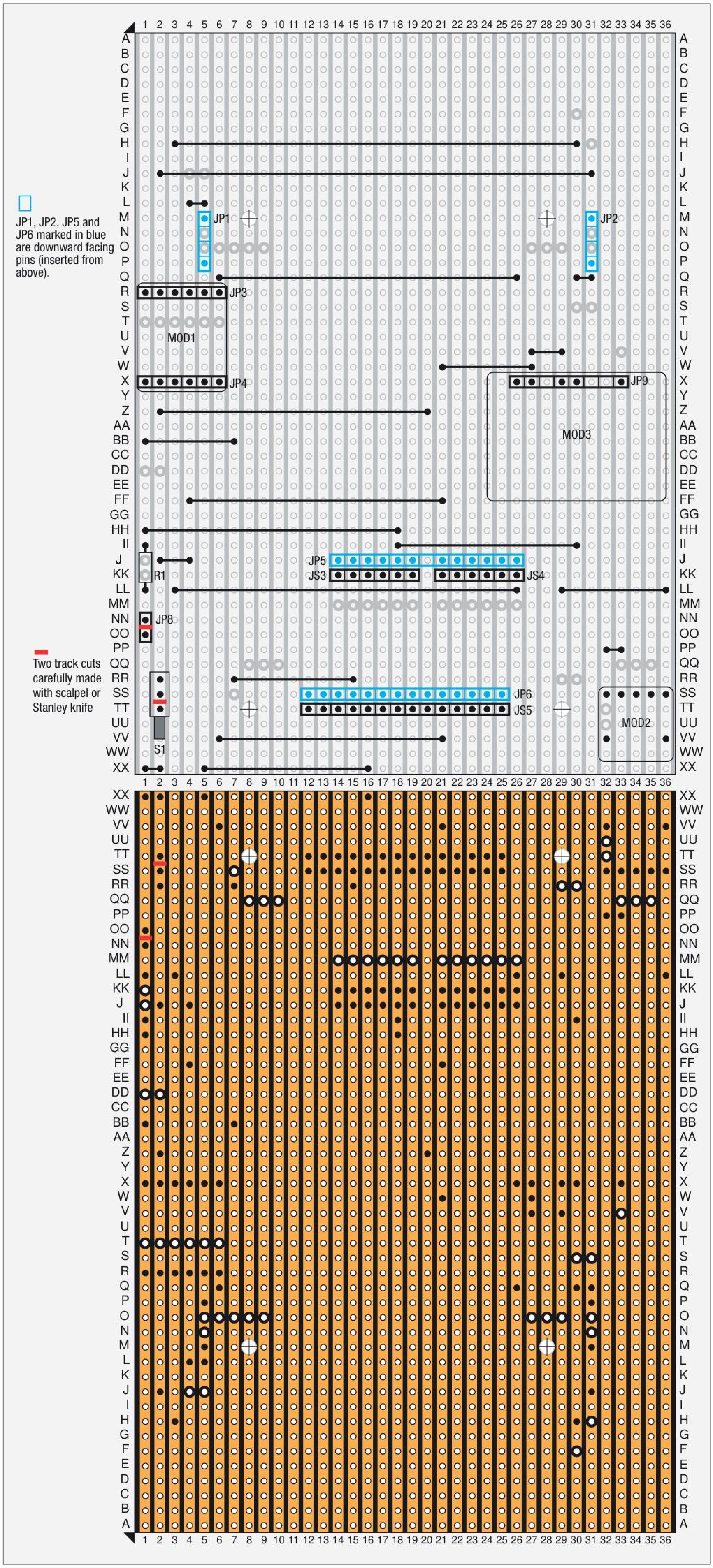
We will now work through two guides for assembling the robot chassis module. Once complete, we will run through some basic testing, and then plug everything together in order to run a simple demo program. Rather than go into extensive assembly details, we will simply provide numbered step-by-step instructions. When used in conjunction with the photos, they should easily provide you with enough information. If at any time you get stuck, or have any questions, then please do get in touch by email. So let's get started…

Table 2: Micromite pin assignments for the *Micromite Robot Buggy.*

Pin No.	Pin function	To module	Robot function
2	I/O	TFT	TFT D/C pin
3	SPI OUT	TFT	TFT SPI IN
4	PWM 1A	MOTOR	Motor 1
5	PWM 1B	MOTOR	Motor 2
6	I/O	TFT	TFT CS pin
7	I/O	TFT	TFT Touch_CS pin
9	I/O	MOTOR	Motor 1
10	I/O	MOTOR	Motor 2
14	SPI IN	TFT	TFT SPI OUT
15	I/O	TFT	TFT Touch_IRQ pin
16	Infrared	TSOP	IR receiver
17	I^{2}C CLK and I/O	–	Available for future use
18	I^{2}C DATA and I/O	–	Available for future use
21	I/O	–	Available for future use
22	I/O	LIPO	EN pin
23	I/O	TFT	TFT RESET pin
24	PWM 2B	–	Available for future use
25	SPI CLK	TFT	TFT SPI CLOCK
26	PWM 2A	TFT	PIEZO Sounder

Assembling the chassis

1. Identify the correct orientation of the acrylic chassis. Fig.2 shows the top surface onto which the daughterboard will be mounted. Fig.19 shows the underside, to which the motors and wheel mounts will be fixed (and this is the side we require now). The orientation is determined by slot SL7,which needs to be on the left, as shown in Fig.19.
2. Push-fit the two wheel mounts firmly into the two sets of four holes, H13 and H14 on the *underside* of the chassis. Ensure that the threaded hole is nearer the outer edge (Fig.19)
3. Place one of the motors into a motor mount so that one side of the gearbox is covered (Fig.16a). Ensure that the gearbox sits into the groves that are inside the motor mount. Before fixing it to the underside of the chassis, we first need to ensure that the motor is inserted with the contacts in the correct orientation. Referring to Fig.15 you can see that one of the motor contacts is marked with a '+' symbol. This needs to be on the left side of the motor mount, when fixed to the chassis. If it isn't, simply flip the motor over in the motor mount. Once correct, fix the motor mount on the underside of the chassis into hole pair H1 using the supplied nuts and bolts (see Fig.16b and 16c). Repeat for the other motor into hole pair H2.
4. Identify the two driving wheels; these have a smaller D-shaped hole in the centre of the wheel (as opposed to a larger round hole) – see Fig.4. Each driving wheel slides onto the D-shaped motor shaft that can be seen in Fig.16b. Align the wheel with the motor shaft and carefully slide one wheel onto each D-shaped motor shaft so that the end of the motor shaft sits flush with the wheel hub. Be careful not to push the wheel on at an angle as this will twist the motor shaft and potentially damage the motor. Note that a fair bit of force may initially be required to get the wheel onto the shaft. Take your time with this step – it is the trickiest part of assembly!
5. The two auxiliary wheels are attached to the two wheel mounts by using the shorter screws (spindles) supplied in the kit (you can discard the longer spindles). Refer to Fig.17 to see the location of the nuts and washers. Screw into the wheel mount and then add the supplied nut to lock it into place (see Fig.19). Check the two axillary wheels spin freely.



JP1, JP2, JP5 and JP6 marked in blue are downward facing pins (inserted from above).

Two track cuts carefully made with scalpel or Stanley knife

Fig.20. Stripboard layout showing position of track-cuts, wire-links, components, and modules.

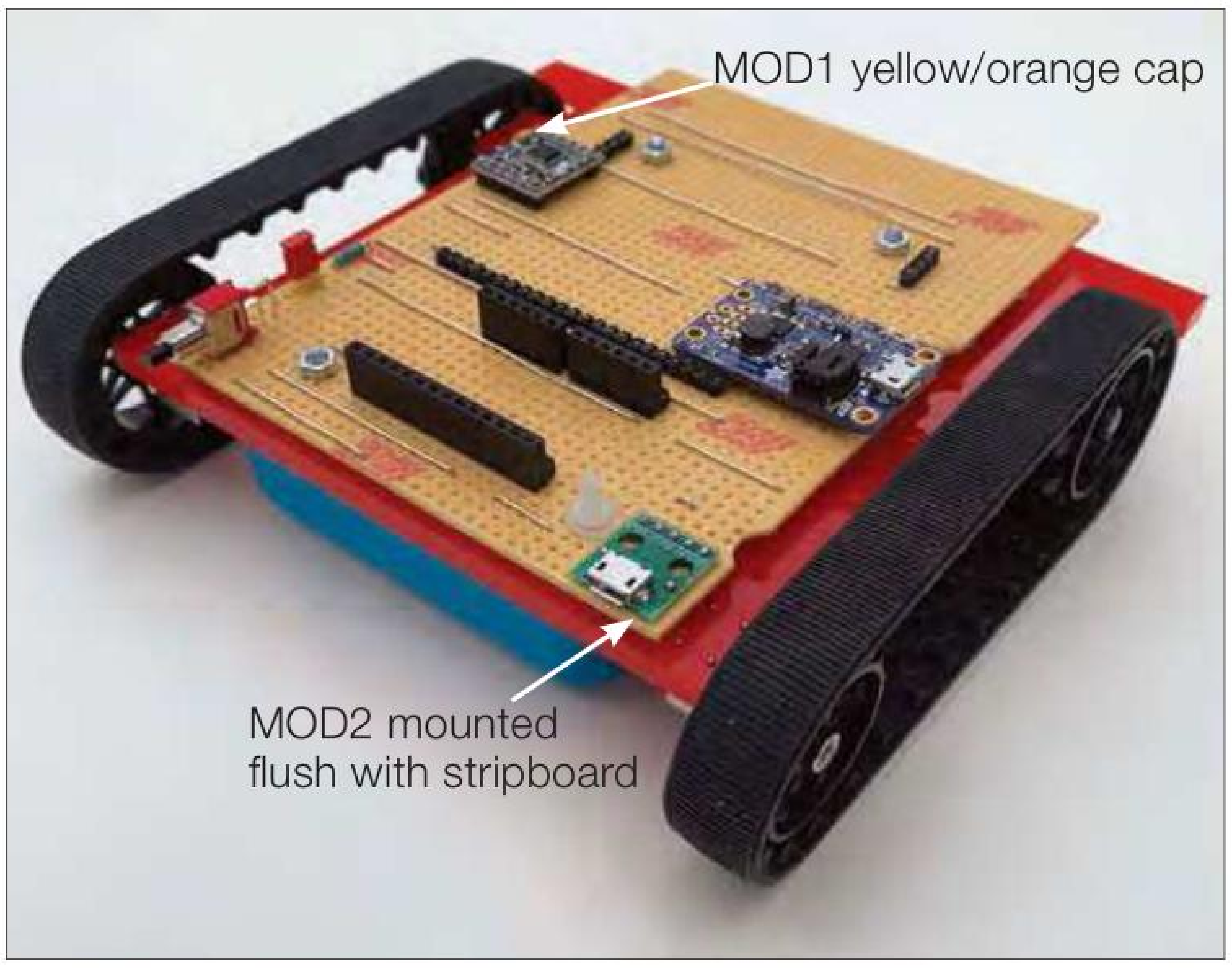


Fig.21. *Robot Buggy* with the daughterboard attached to the chassis. The *MKC* and Bluetooth modules are attached on the underside. TFT module yet to be attached.

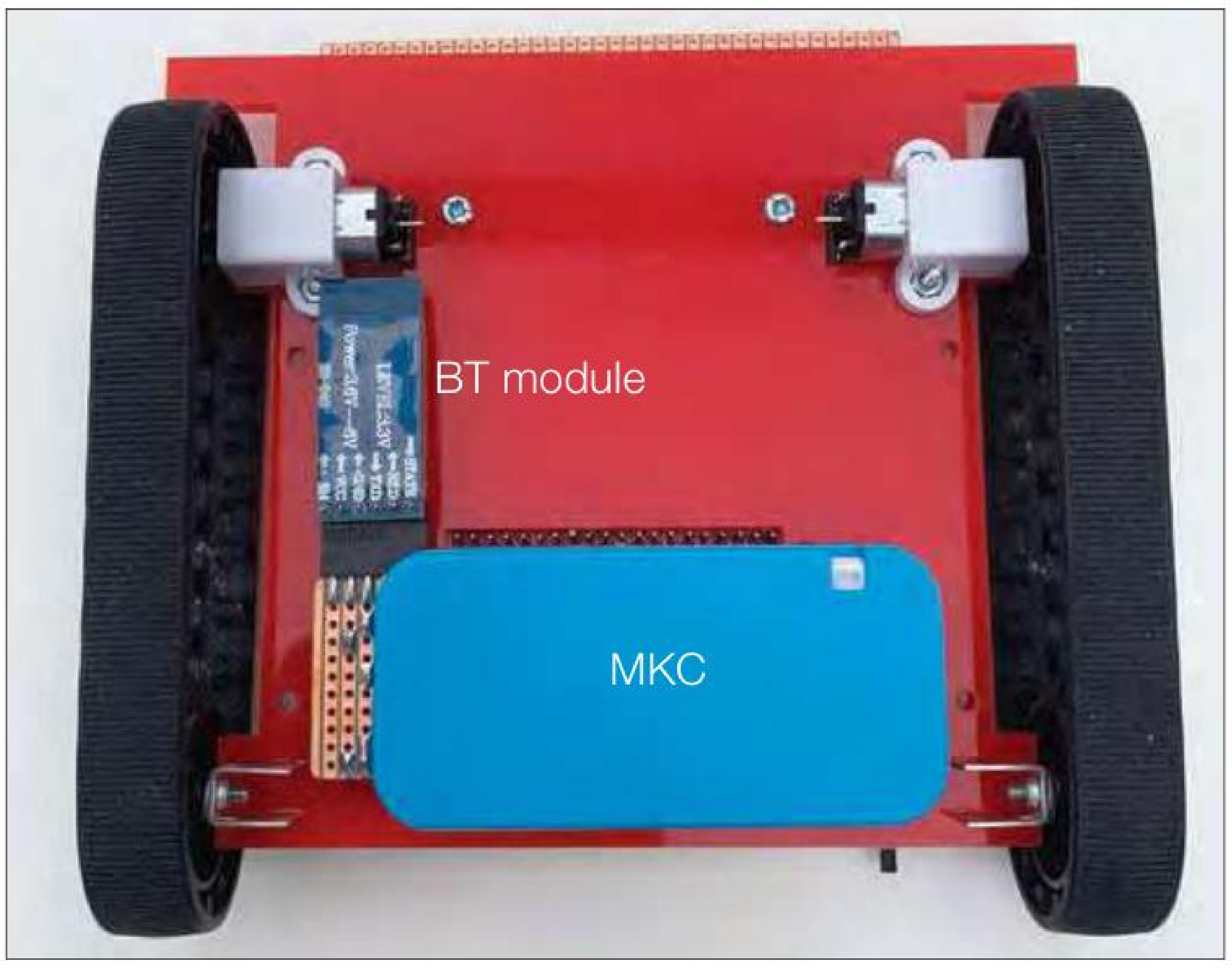


Fig.22. The underside of the *Robot Buggy* with the *MKC* and Bluetooth module attached.

6. Place the two tracks over each pair of wheels. Ensure the track teeth sit properly around the toothed wheels (Fig.4). Then, manually turn each track slightly to check that the wheels turn – you will probably hear the gearbox mechanism turning as you do this.
7. Take the four 12mm, M3 nylon screws and from the underside of the chassis, insert them into holes H3, H4, H11 and H12. Use four of the nylon nuts to hold the screws in place. These four upward-facing screws will be used later as mounting posts to position the daughterboard onto the chassis (and the four remaining nylon nuts will secure it down).

That completes the chassis assembly. Do check that everything seems correct and ensure that you address any issues before moving on. We will now work through the assembly of the daughterboard.

Assembling the daughterboard

Throughout the following steps, refer to Fig.20 for the layout of the stripboard.

1. Mark the position of all the track cuts. *Check them all at least twice before making the cuts!* Be sure to remove any shards of track to avoid shorts with neighbouring tracks.
2. Mark the four positions (M8, M28, TT8, TT29) of the mounting holes shown in Fig.20. Use a 3mm drill bit to make the holes.
3. Mark the locations of the 20 wire links. Tip: use a felt-tip pen and mark the 'start' and 'end' holes on the top-side of the stripboard. Check these at least twice, making any corrections. Then simply work through one link at a time by wiring up the 'felt-tip dots'. Check that there are no solder shorts to neighbouring tracks.
4. Prepare all pin-strips (JP*xx*) and sockets (JS*xx*) as shown in Fig.14 (carefully observing where pins and contacts need to be removed from the plastic body)
5. The motor driver module (MOD1) has a solder-link on the underside – ensure that this is shorted out with a blob of solder.
6. Solder the two 6-way pin-strips (JP3 and JP4) onto the underside of motor module MOD1, and then solder the module into position on the daughterboard. Ensure that the yellow/orange capacitor on the motor driver module is towards the upper-left corner – refer to Fig.21.
7. Solder the modified 8-way pin strip (JP9) into position on the stripboard. Ensure that only 5-pins are in the modified 8-way pin-strip (as shown in Fig.14), and also that it is mounted the correct way round (refer to Fig.20). *Do not solder* the LiPo module yet!
8. Position the USB BoB (MOD2) directly onto the stripboard. Use the 5-way pin-strip (JP7) and insert the long pins down through the USB BoB continuing down through the stripboard into holes SS32-SS36. Solder the pins to the stripboard. Next, carefully remove the plastic from the pin-strip on the USB BoB side by sliding it upwards. Now you can solder the pins to the top side of the USB BoB. This process ensures that the BoB is fixed down flush onto the strip-board. See Fig.21 and Fig.23.

   Finally, solder two wire-link off-cuts into hole positions VV32 and VV36. These add strength by holding the USB BoB down onto the stripboard.
9. Solder the power button (S1) into place. (Remember to make track cut first – see Fig.20.)
10. Solder the 10kΩ pull-down resistor (R1) into place.
11. Solder the 2-way jumper link (JP8) into place. For now, do not insert the jumper link. (Remember to make track cut first – see Fig.20.)
12. Solder the two modified 4-way pin-strips (JP1 and JP2) into position. Insert them from the upper side so the pins point downwards. Once soldered, slide on the two modified 4-way sockets, (JS1 and JS2). These sockets will be soldered directly to the two motors later (once the daughterboard is mounted onto the acrylic chassis).
13. Solder the 13-way pin-strip (JP5) and the 14-way pin-strip (JP6) into place. These are both downward facing and will ultimately allow the *MKC* plus Bluetooth module to be attached to the underside of the robot, as shown in Fig.22 and Fig.23.
14. Solder the two 6-way sockets (JS3 and JS4) along with the 14-way socket (JS5) into position. These will allow *MIWM* modules to be plugged into the robot from above, such as the TFT module.

That completes the assembly of the daughterboard for now. If you have followed the above steps, then the LiPo Charger/Booster module (MOD3) will not be installed. This is important as we will test the daughterboard first *before* we solder MOD3 into place. Once again, do a thorough visual check and correct any issues. The circuit is not complex so there really isn't much that can go wrong other than accidental shorts between tracks, or missed track-cuts. I recommend you take a break now, and come back to it another time and do one final check before moving on.

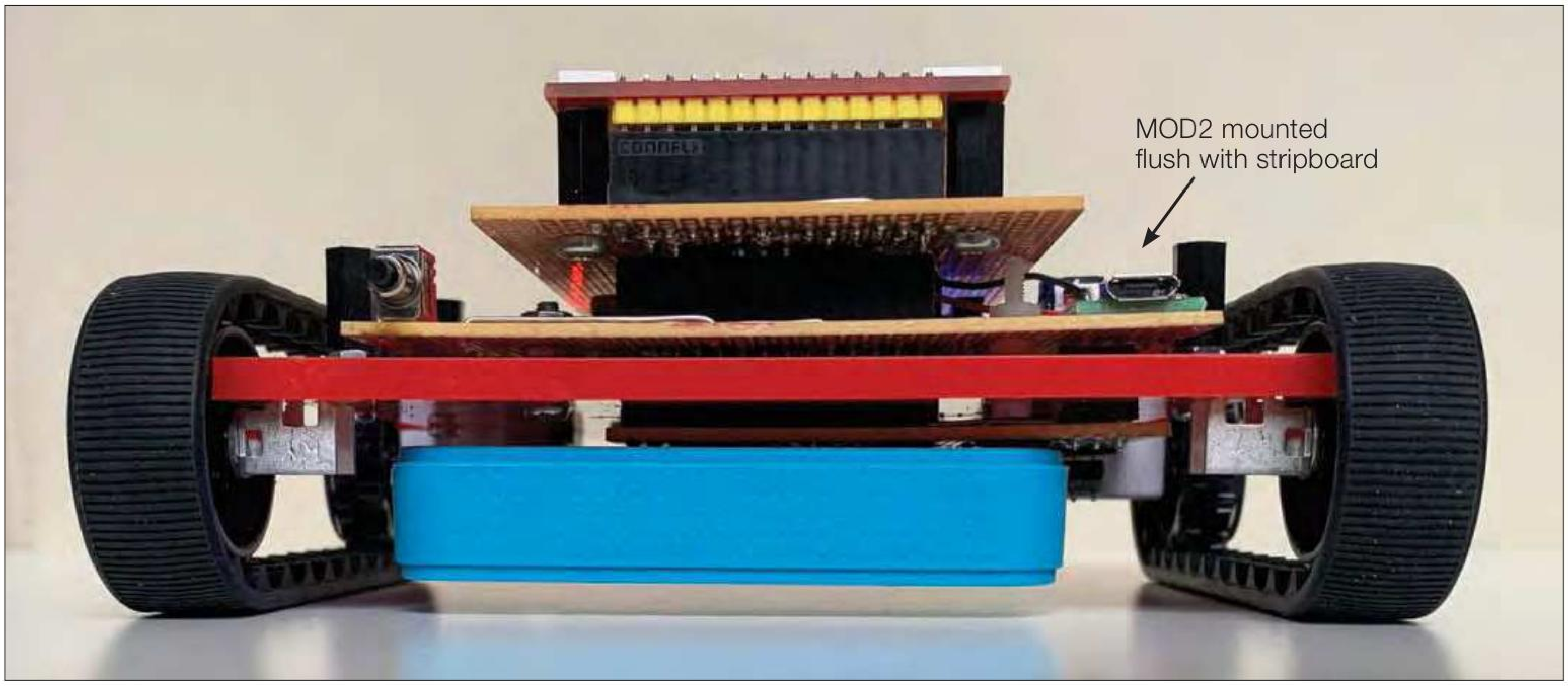


Fig.23. The *MKC* and Bluetooth module correctly attached provides sufficient ground clearance (even though it looks close!).

Mounting the daughterboard

We will now mount the daughterboard onto the chassis so that we can test that the motors operate correctly. Begin by taking the Bluetooth (BT) module and inserting it through the chassis from below. You should find that the four Bluetooth sockets will pass through slots SL5, SL6. SL7 and SL8. If not, then you may just need to 'assist' them through. Once in place, offer up the daughterboard aligning it with the four nylon screws. You now need to line up the two rows of downward facing pins (JP5 and JP6) and insert them into the BT module. You may also need to bend the two pairs of 4-way motor connectors (JS1 and JS2) through slots SL1 and SL2 in order for everything to fit correctly. Once in place, use the four remaining nylon nuts to fix the daughterboard to the chassis. Tighten these nuts fully. Next, remove the BT module and you should then see that the daughterboard pins are reasonably central when viewed from below, as shown in Fig.19. Note that the longer slot SL3 is not currently being used, so ignore the pins that you can see in SL3 in Fig.19.

Now we need to solder the two motors to the two modified 4-way sockets (JS1 and JS2) that should be poking through slots SL1 and SL2. Refer to Fig.15 to see how the end result should look. The sockets can be re-positioned as they are currently only slid onto JP1 and JP2 on the daughterboard. An important point (if using 'extended' shaft motors) is not to let the plastic housings on JS1 and JS2 touch the motor shaft. If they do, then the motor(s) won't turn correctly. So go ahead and position the sockets as required, and then solder them carefully to the motors. Be careful not to slip with the soldering iron as this could melt the plastic on the back of the motor (yes, I did just that on an early version). Cut off any excess socket contact so that you end up with something similar to that shown in Fig.15. Now we are in a position to test the motors.

Testing the motors

At this stage, you should have the *MRB* daughterboard firmly attached to the chassis. The LiPo Charger/Booster module should not be installed, and no *MIWM* hardware should be attached (not even the *MKC* or BT modules).

For the motor test, a 5V power source is required along with six (male-to-male) jumper wires, and a small breadboard (or equivalent).

The idea behind this test is to power the daughterboard with the 5V supply, and then connect 0V and 5V DC to one pair of input pins on the motor driver module (eg, IN1 and IN2 on MOD1). If everything is OK, then this will spin one of the *MRB* tracks in one direction. Swapping the polarity to IN1 and IN2 should reverse the motion. The test is then repeated by supplying 5V DC to the other pair of input pins (IN3 and IN4), which should spin the other track. Again, the spin direction is determined by the polarity applied to the input pins.

You can use your *MKC* as the 5V power source by 'tapping into' the two end pins on the 6-way socket (0V closest to USB-micro socket). Use two jumper wires to connect 0V and 5V from the *MKC* to the breadboard, and then use two more to feed 0V and 5V (from the breadboard) to the 0V and 5V positions on JS4 – see Fig.18.

Now power up your *MKC* as normal and check that its power LED is lit. For clarity, there is no need to launch your terminal app – you simply need to power up your *MKC*. Your daughterboard is now powered up. Depending on the version of MOD1, you may see an LED on the motor module light up.

If the *MKC's* power LED is not lit then there is a problem; check its power source, and also the correct connection of the four jumper wires.

With the *MKC's* power LED lit, the remaining two jumper wires are used to supply 0V and 5V DC to one of the two input pairs on the motor module. Use one jumper wire to supply 0V (from the breadboard) to pin 4 on JS5 (IN1 on MOD1), and the other to supply 5V (from the breadboard) to pin 9 on JS5 (IN2 on MOD1). This should result in one track rotating so you will need to hold the robot off your workbench. If a track doesn't rotate then you will need to check for shorts, all jumper wire connections, and the 12 solder joints on MOD1.

When you have achieved successful movement of a track swap the jumper wire to pins 4 and 9 on JS5, and check the same track now rotates in the opposite direction. Once this is functioning correctly, you can remove the wires from pins 4 and 9, and carefully insert them into pins 5 and 10. Repeat the test to ensure the other track can rotate in both directions. Once complete, power down your *MKC*, and remove all six jumper wires.

Take your time and all will be well, but if you're totally stuck, then send me an email and attach a high-resolution photo of the underside (track-side) of your daughterboard. This will mean dis-assembling your robot by undoing the four nylon nuts, and then carefully unplugging the daughterboard from the two motor sockets.

When you have successfully completed the motor test you can proceed to the final assembly task.

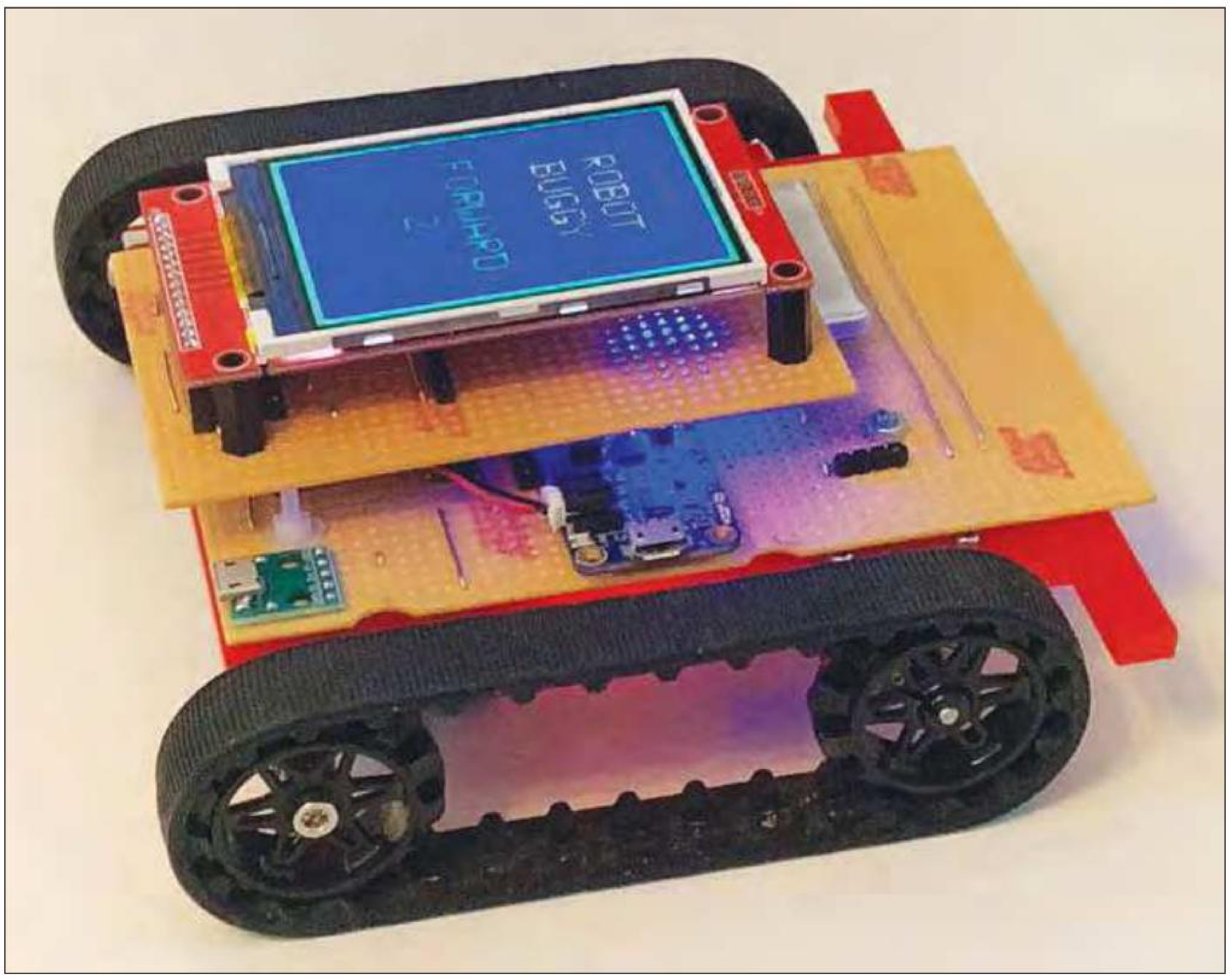


Fig.24. The *Micromite Robot Buggy* (with the TFT module attached) running the MicromiteRobotBuggy_Demo1 program.

Final assembly

We will soon solder the LiPo charger/booster module into place but before doing that, let's quickly check that it works. Connect the LiPo battery to the LiPo module, being careful to ensure you insert the battery's 2-pin JST connector the correct way round. The JST connector is shaped in such a way that the battery can only be inserted in one orientation. As a sense check, the battery's black lead will be closest to the corner of the module. On inserting the battery, the module's power LED (typically a blue one) should light up. This confirms the module is functioning correctly. If the LED does not light up, be sure that the module is not sitting on anything conductive! If the LiPo is 'dead' then that could be the issue; however, LiPo batteries typically have protection circuit built in that prevents them totally running flat. If the LiPo module's power LED doesn't light up, plug a 5V PSU directly into the micro-USB socket on the charger module (this is a charging input). On doing this, you should see the recharging LED illuminate (orange or green). If so, then let the battery recharge for a short while. If there is still no LED that lights up then you will need to check the battery is inserted correctly. If you still have problems then try another LiPo battery.

Once you see the LiPo module's power LED light up, carefully remove the LiPo battery. Do not pull on the delicate battery leads to do this – they are very delicate! With the battery removed, go ahead and solder the module onto the five protruding pins on the 8-way pin-strip (JP9) on the daughterboard (refer to Fig.18, 20 and 21 to confirm placement). Now install the jumper-link onto the 2-way pin-header (JP8).

With the LiPo module installed, and the jumper-link in place, carefully re-connect the LiPo battery. Next, do a quick power test by pressing the power button (S1). Upon pressing the button, the LiPo module's power LED should light up indicating that 5V power is output from MOD3. However, as soon as you release the power button, the power LED should turn off. With the button released (and the MOD3 power LED off), remove the 2-way jumper link and check the MOD3 LED comes back on. If any of these tests fail then you will need to check all the tracks concerned with power circuit – use the stripboard layout in Fig.20 to assist with this.

Once both the motor circuit, and the power circuit have been successfully tested, plug the Bluetooth module into your *MKC*, and connect them to your robot by plugging them into the underside of the robot (Fig.22). Ensure that these are pushed fully into place so that there is sufficient clearance from any flat surface that the robot is placed onto (Fig.23).

Next, carefully plug in the TFT module ensuring that all the pins on the TFT module insert into the sockets (JS3, JS4, and JS5) correctly. Finally, remove the 2-way jumper link to power up the *MRB*.

Robot demo software

Your Micromite robot buggy is now ready to be tested from your remote computer by using the demo program that we have written. The program allows you to control (ie, move) the robot buggy by prompting you to enter a direction, and a duration. The program also confirms that you still have wireless remote access between your terminal app and your 'mobile' *MKC*. You need to download the file **MicromiteRobotBuggy_Demo1.txt** from the June 2020 page of the *PE* website.

With the power-jumper link off, the TFT module inserted, and with the LiPo battery plugged into the LiPo Booster/Charger module, install the code onto your *MKC* and run the program. If all is well you should hear an initial beep (if you have the piezo sounder installed on your TFT module), and you should also see a colourful 'MICROMITE ROBOT BUGGY' message on the TFT. In your terminal app you should be prompted to enter a direction in the form: (F)orward, (B)ack, (L)eft, (R)ight, (O)FF. Press the 'F' key (Enter) and then enter a low-value duration such as 2. On pressing the Enter key your robot buggy should move forwards a short distance, and then stop. Upon completion of the move, you should hear a short beep from the piezo. You should also be able to see the direction and duration value on the TFT screen (as shown in Fig.24). Check the other three directions (B, L and R) also function as expected. Now return the jumper link to JP8. Finally, select the 'O' option and check that the robot turns off.

This is only a simple test demo to check the basics – if any of the tests fail, then take your time checking things over. Remember that all we have essentially done is add a battery, and a set of wheels, to your existing (working) *MKC*, Bluetooth, and TFT modules. If you have successfully reached this point then congratulations – you have successfully assembled your *Micromite Robot Buggy!*

Next Month

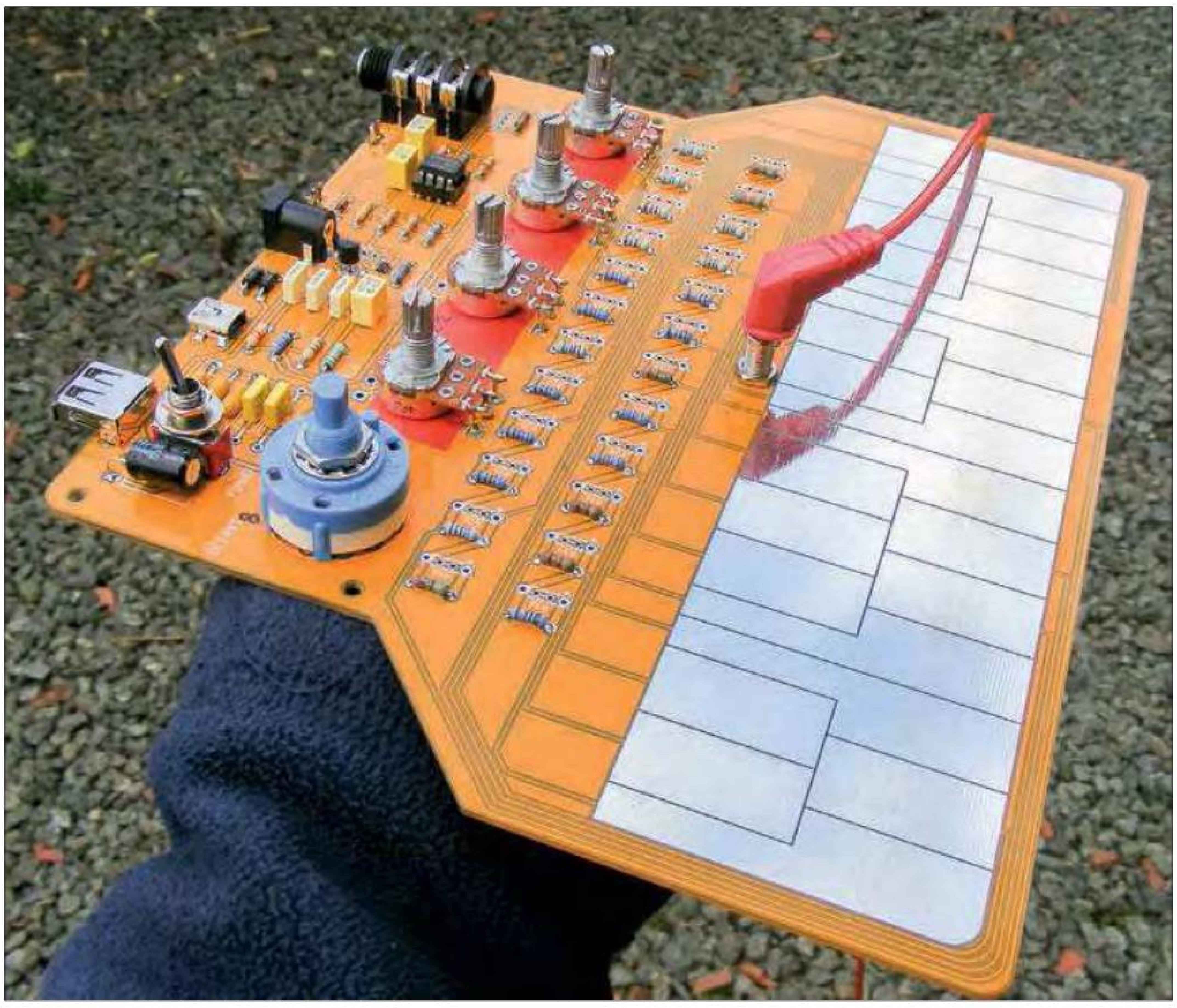
Having assembled the robot chassis module, you now have a basis on which to add some other features (and hence add some personality to your robot). So next month we will show you how to add some animated eyes (in the form of two 8×8 LED matrix modules). In addition, we will add an IR receiver to control various robot features from an IR remote. In the meantime, why not write some code to make your robot automatically follow a sequence of steps (movements and turns) so that it moves around on a defined path. Then make it repeat this path over and over. Have Fun!

Questions? Please email Phil at:
contactus@micromite.org

AUDIO OUT

By Jake Rothman

PE Mini-organ – Part 1



The *PE Mini-organ*

I'm writing this during the pandemic but also still suffering from February's storm damage, which means no Internet, TV or landline – the mobile works in just one room, badly. All that really works is FM radio. This has brought home the fragility of our interconnected global society and dependence on tenuous component supply chains. Even my solar panels are useless because they need power from the grid to run the inverter. What a mess, but at least there's still Cadbury's Chocolate and AA cells.

Looking on the bright side, I don't feel guilty for being a hoarder any more. Glancing smugly at my vast piles of dust-covered components and burnt data-sheets, it's a great time to do some low-power analogue circuit design.

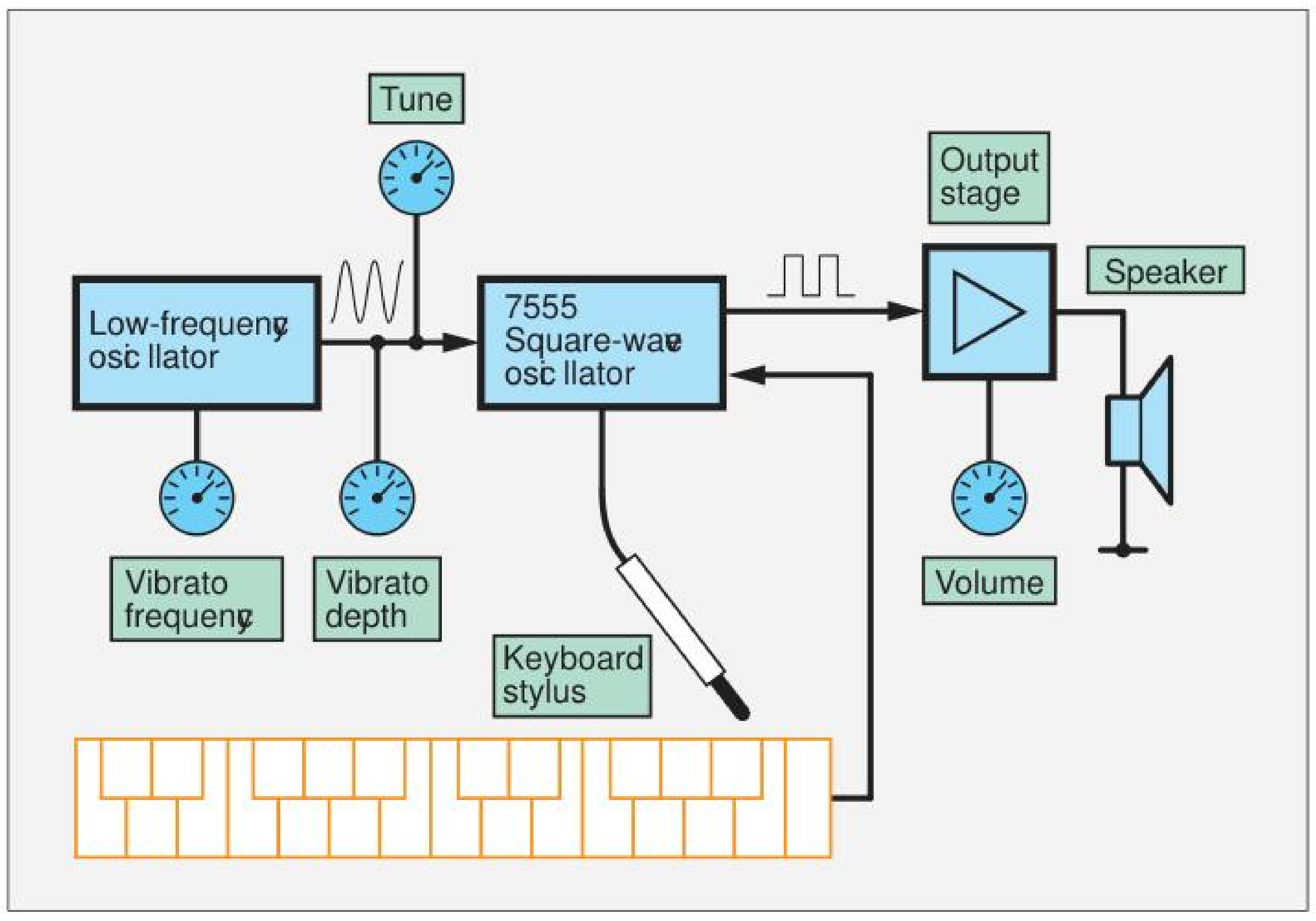


Fig.1. The basic system consists of a CMOS 7555 square-wave oscillator, a vibrato oscillator and a unique output stage.

Student projects

All educational establishments are closed now, so I thought I would get a nice pile of student projects finished for when everything restarts. An eternal favourite is the Stylophone, but all previous designs have had problems. My version presented here has a big Mike-Grindle-designed wide-spaced through-hole PCB. There are only two (optional) surface-mount components: a mini-USB (everybody needs to learn how to solder these since they regularly break) and an output transistor option. There are three traditional analogue stages and a 4×AA battery-pack, which lasts for days. The keyboard resistor-chain is a nice challenge for those learning the resistor colour code. (Top tip, do check every resistor with a good DMM – if you get just one resistor wrong then it will upset *every* note.)

Basic design

This *PE Mini-organ* is based on a provisional design I did for *Audio Out* (*EPE*, August 2018 Fig.11). This was later refined to produce a design for Dubreq, which became their new *Analogue Stylophone*, an ultra low-cost surface-mount design. (This will of course be cheaper to buy than building the instrument described here when it becomes available. However, that's not the point, building your own is always so much more than just the final result).

The analogue version is cheaper to make and uses around a fifth of the power of the *Stylophone S1* digital design. It also sounds nicer, having no aliasing and other high frequency whistles. Incidentally, this 'analogue renaissance' in electronic music is now an established marketing angle to boosts sales. Of course, the main disadvantage with analogue is tuning accuracy. There is always more drift with a capacitor as the heart of a timing element compared to a numerical divided-down quartz or ceramic resonator. There's no need to worry too much about this for a 'toy' instrument. I don't think a Stylophone has ever been used in an orchestra; it's pinnacle was probably David Bowie's *Space Oddity*. (**https://youtu.be/iYYRH4apXDo**).

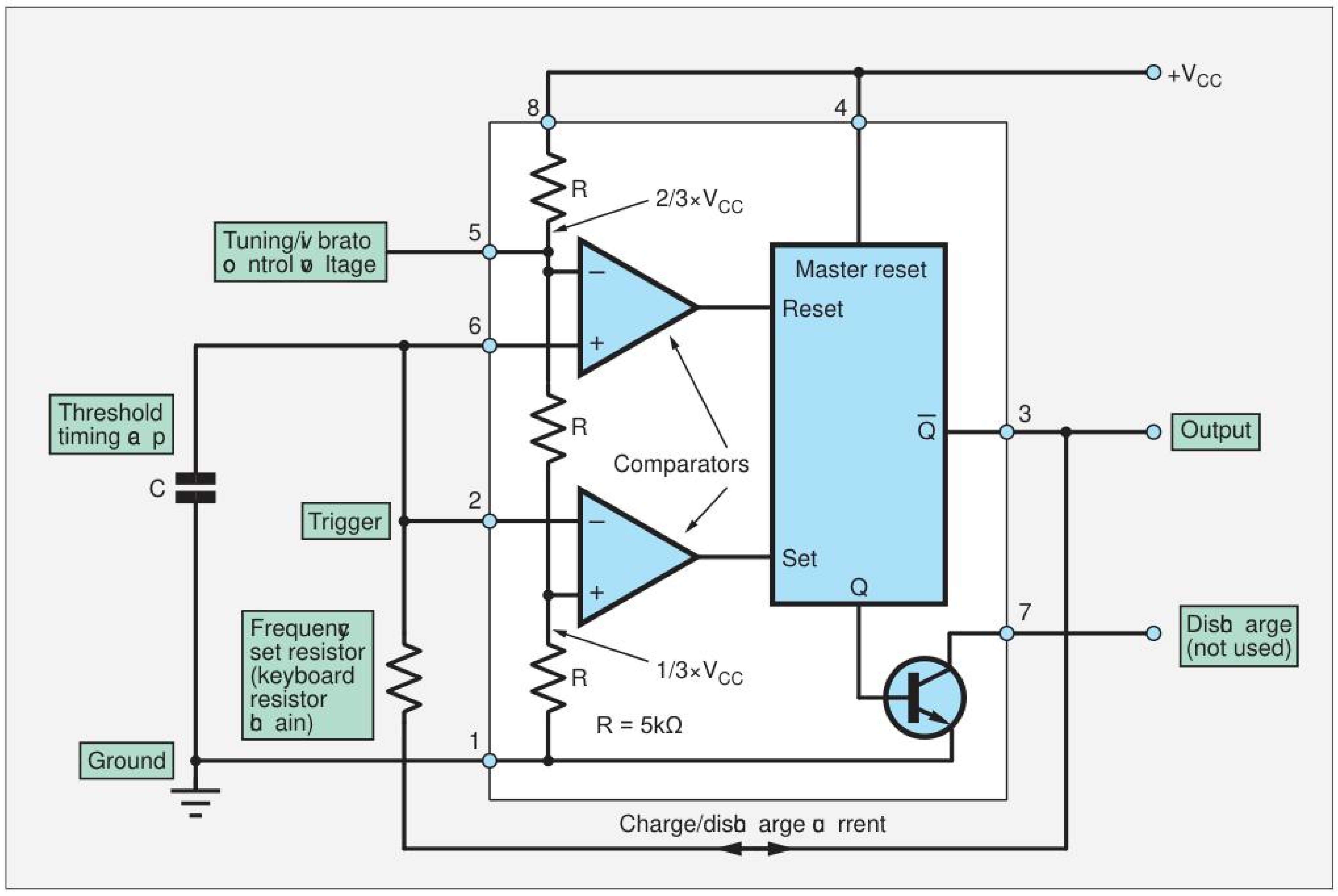

+VCC
8
4
R
2/3×VCC
Tuning/vibrato control voltage
5
Master reset
Reset
6
Threshold timing cap
C
R
Comparators
Q̄
3
Output
Trigger
2
Set
Q
7
Discharge (not used)
Frequency set resistor (keyboard resistor chain)
R
1/3×VCC
R = 5kΩ
1
Ground
Charge/discharge current

Fig.2. Internal circuit of a CMOS 7555. Is it analogue or digital? I would say both.

Block diagram

The basic system is a 555 square-wave oscillator controlled by the keyboard. This is modulated by a phase-shift low-frequency oscillator to provide vibrato. The output wave is fed into a MOSFET speaker driver. That's a 20p chip with two 5p transistors, about right for a student project – see Fig.1.

I make no apologies for using the good old 555-timer chip for the oscillator. It was used in the original Stylophone designs from the late 1970s. Internally, the chip uses a chain of three resistors to define the top and bottom comparator-switching thresholds (see Fig.2). Since these thresholds are ratio-based, the output frequency does not vary much with supply voltage or temperature. It is stable enough for a *Mini-organ* run off batteries with no voltage regulator. In its CMOS version (called the 7555), as used here, the power consumption is less than 0.2mA. This chip could be considered an analogue/digital hybrid. Are comparators analogue or digital? Here, it is used in an analogue way with a capacitor that charges up.

The circuit diagram is shown in Fig.3. It looks challenging for a beginner, but it's not when broken down into its functional blocks. The internal operation of the 555 has been well covered before. Pin 5 allows a degree of voltage control of the frequency. The output of the tuning control (VR1) and the vibrato oscillator are summed here.

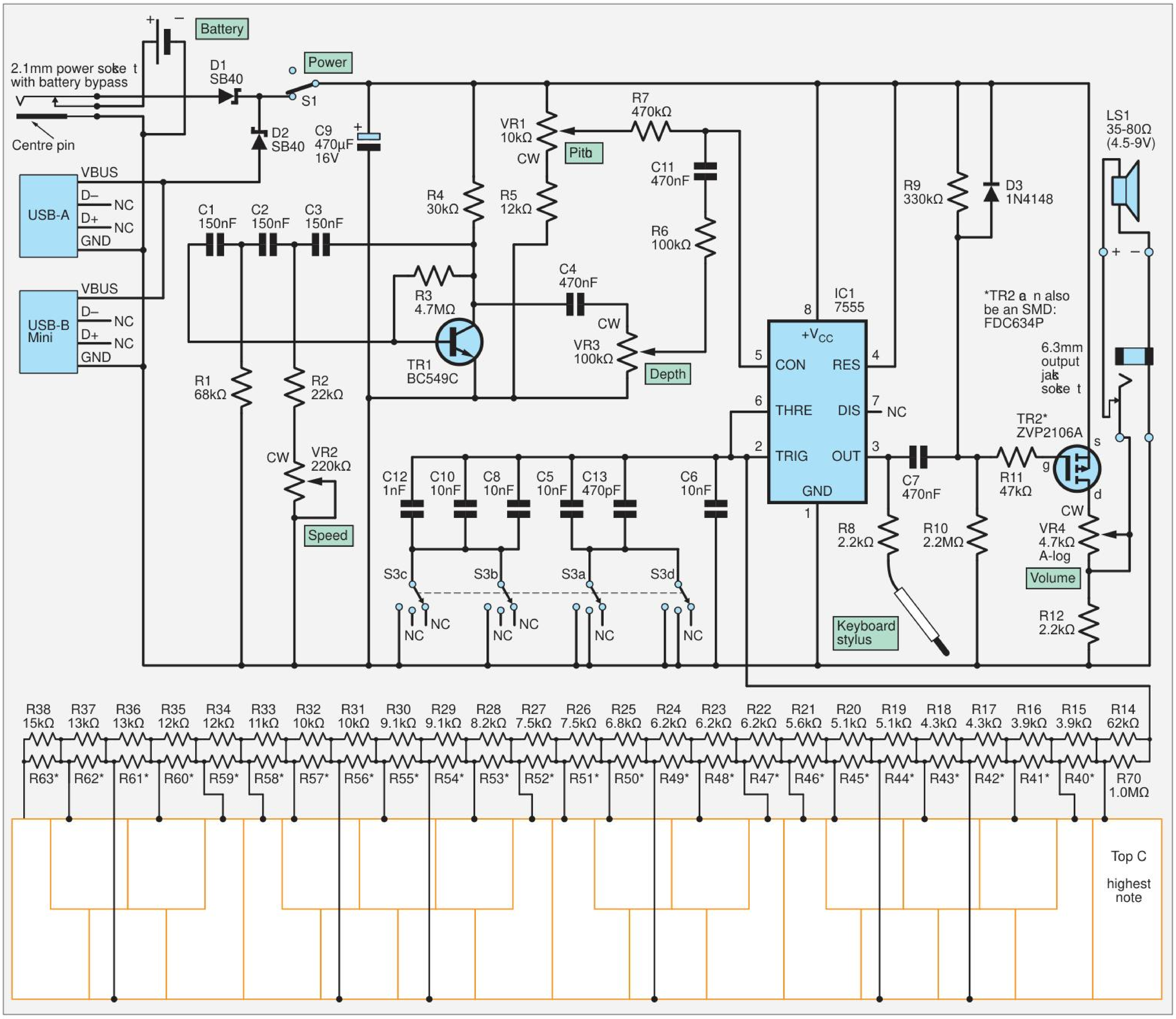

Battery
+
–
2.1mm power socket with battery bypass
Centre pin
D1 SB40
Power
S1
D2 SB40
C9 470µF 16V
VBUS
USB-A
D–
D+
NC
GND
VBUS
USB-B Mini
D–
D+
NC
GND
C1 150nF
C2 150nF
C3 150nF
R1 68kΩ
R2 22kΩ
CW
VR2 220kΩ
Speed
R3 4.7MΩ
TR1 BC549C
R4 30kΩ
R5 12kΩ
VR1 10kΩ
CW
Pitch
R7 470kΩ
C11 470nF
R6 100kΩ
C4 470nF
CW
VR3 100kΩ
Depth
IC1 7555
8
+VCC
5
CON
RES
4
6
THRE
DIS
7
NC
2
TRIG
OUT
3
GND
1
C12 1nF
C10 10nF
C8 10nF
C5 10nF
C13 470pF
C6 10nF
S3c
S3b
S3a
S3d
NC
R9 330kΩ
D3 1N4148
C7 470nF
R8 2.2kΩ
R10 2.2MΩ
Keyboard stylus
*TR2 can also be an SMD: FDC634P
LS1 35-80Ω (4.5-9V)
6.3mm output jack socket
TR2* ZVP2106A
s
g
d
R11 47kΩ
CW
VR4 4.7kΩ A-log
Volume
R12 2.2kΩ
R38 15kΩ
R37 13kΩ
R36 13kΩ
R35 12kΩ
R34 12kΩ
R33 11kΩ
R32 10kΩ
R31 10kΩ
R30 9.1kΩ
R29 9.1kΩ
R28 8.2kΩ
R27 7.5kΩ
R26 7.5kΩ
R25 6.8kΩ
R24 6.2kΩ
R23 6.2kΩ
R22 6.2kΩ
R21 5.6kΩ
R20 5.1kΩ
R19 5.1kΩ
R18 4.3kΩ
R17 4.3kΩ
R16 3.9kΩ
R15 3.9kΩ
R14 62kΩ
R63*
R62*
R61*
R60*
R59*
R58*
R57*
R56*
R55*
R54*
R53*
R52*
R51*
R50*
R49*
R48*
R47*
R46*
R45*
R44*
R43*
R42*
R41*
R40*
R70 1.0MΩ
Top C highest note

Fig.3. Full circuit of the *PE Mini-organ.*

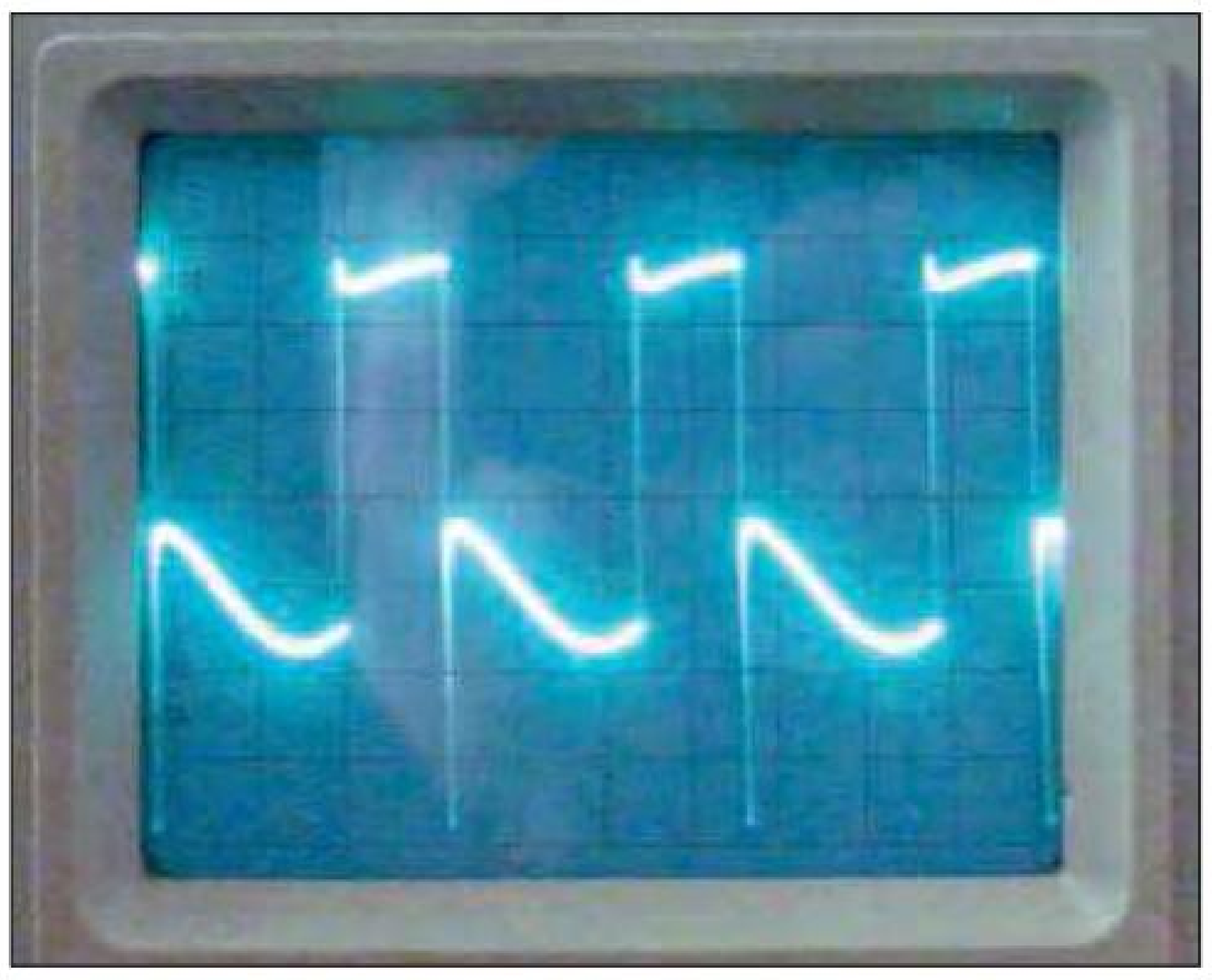


Fig.4. *PE Mini-organ* output waveform viewed across the speaker. The ringing is the resonant back electromotive force voltage (EMF) from the speaker.

Power supply

The *PE Mini-organ* operates from 3.5 to 12V. Current consumption is 0.2mA with no note playing. Average current when played is 12mA, and a continuous note at full volume draws 40mA. The current consumption is minimised by having an uneven mark-to-space ratio on the output waveform – off more than it is on. The waveform is shown in Fig.4. Power supply connections options are provided via a 2.1mm DC connector, a standard USB socket and a mini-USB version. Schottky diodes D1 and D2 block back current passing from the battery. (I don't know what happens if you put 9V into a USB socket on a laptop and I don't want to test it). The 7555 goes up in smoke if the power is connected the wrong way and these diodes also provide reverse-polarity protection. The current from standard batteries is limited which avoids most damage, but power supplies will generally supply enough current to start a fire.

Note that the 2.1mm connector follows the 'guitar-pedal standard', which is centre-pin negative. Watch out for this when using 'off-the-internet' 'wall-warts' that are generally the other way round.

Octave switching

An octave interval is simply a doubling or halving of frequency. In a digital system, to go down an octave, a divide-by-two stage (eg, a flip-flop) would be used. Since the *PE Mini-organ* is an all-analogue design, we are just going to double or halve the value of the timing capacitor.

Three octave ranges are available and the total capacitance for each range is 10nF, 20nF and 40nF respectively, selected by a rotary switch. Although very simple in principle, there are problems with this approach because capacitors have wide tolerances, causing the octaves to not be exact. ±5% is the best specification for cheap capacitors, such as ceramic NP0 types. We could use 1% polystyrene or silvered-mica versions but they are scarce and pricey. However, it is the ratios between the capacitors that matter, rather than the absolute value. I've have found 5% capacitors taken from adjacent positions of the same reel are accurate enough because there is generally little variation between each one in the same production batch. One batch I had were all around 9.6nF with a maximum of 9.65 and a minimum of 9.42nF. So what I have done here is use parallel capacitors from the same batch to create accurate doubling of capacitor values. C6 provides the first (top) octave. For the second octave, C5 is switched in parallel. For the final (lowest) octave, C10 and C8 are added in parallel.

The rotary switch specified can be a pain to wire up, but it's nice and easy when soldered directly to a PCB where all the 'wiring' is done for you. Mike Grindle even paralleled-up the unused sections, a standard technique which improves reliability. You've already paid for those contacts, so why not use them?

All oscillators have a tendency to go a bit flat as they go higher in frequency due to their finite switching time. To compensate for this, the upper octave capacitor (C6) has to be a bit smaller than the lower ones (C5, C8/C10). If you have access to a capacitance meter and you find you have a variation between them, the lowest value should be used for C6 and the highest for C10. (Optional) padder capacitors C12 and C13 are provided to deal with this.

Keyboard

The big problem in musical electronics is that most oscillators are linear and musical scales are exponential. This is because human senses are logarithmic; it's the way biological organisms handle the huge range of intensity of the various stimuli encountered in nature. The way round this is to make the keypard resistor value increments non-linear, so that the notes increase in the correct musical steps (the twelfth root of two if you need to know). The editor and I nearly had breakdowns typing the calculations and ratios for the keyboard resistors last time (in *Audio Out*, *EPE*, August 2018 p.56) so we're not going to go through it again! The problem here is to get the right value resistors in the right holes. For those who are obsessed with getting the ratio exactly right (1.0595) there are spare positions for parallel resistors and or presets. Most people are happy with the standard 1% E24 series resistors. Resistor R14 is critical to the scale of the whole keyboard from the top octave to the bottom. If you find the top 'C' is flat compared to the bottom 'C' it will be necessary to tweak it a bit. I had to add a 1MΩ resistor (R70) in parallel with R14 to bring it into line.

Modulation oscillator

This is a standard phase-shift sinewave oscillator consisting of three capacitors (C1 to C3) and two resistors. This network is placed in a negative feedback loop around a standard common-emitter stage. At the frequency where the network phase lag hits 180°, the feedback becomes positive, and oscillation commences. On the original design the vibrato modulation level and frequency were fixed. Since we are less limited by size and cost in home construction, pots are provided for level/depth (VR3) and frequency (VR2). Note that as usual in audio RC oscillators, the frequency potentiometer must be anti-logarithmic to give a smooth adjustment range.

Output stage

Since the waveform is basically a square wave (see Fig.4) a linear audio amplifier, such as an LM386, is not required. A simple 'switch' will do. A bipolar common-emitter stage could be used, but the CMOS 7555's output drive current capability is too low, so a MOSFET with its high input impedance has been used. This stage is wired 'upside down' so the speaker goes to the ground rail using a P-channel device rather than the more common N-channel with the speaker going to the power rail. This approach is needed so that the output is ground referenced, allowing external amplifiers to be connected via a jack socket.

The volume control is a bit unusual in that it is simply a variable resistor

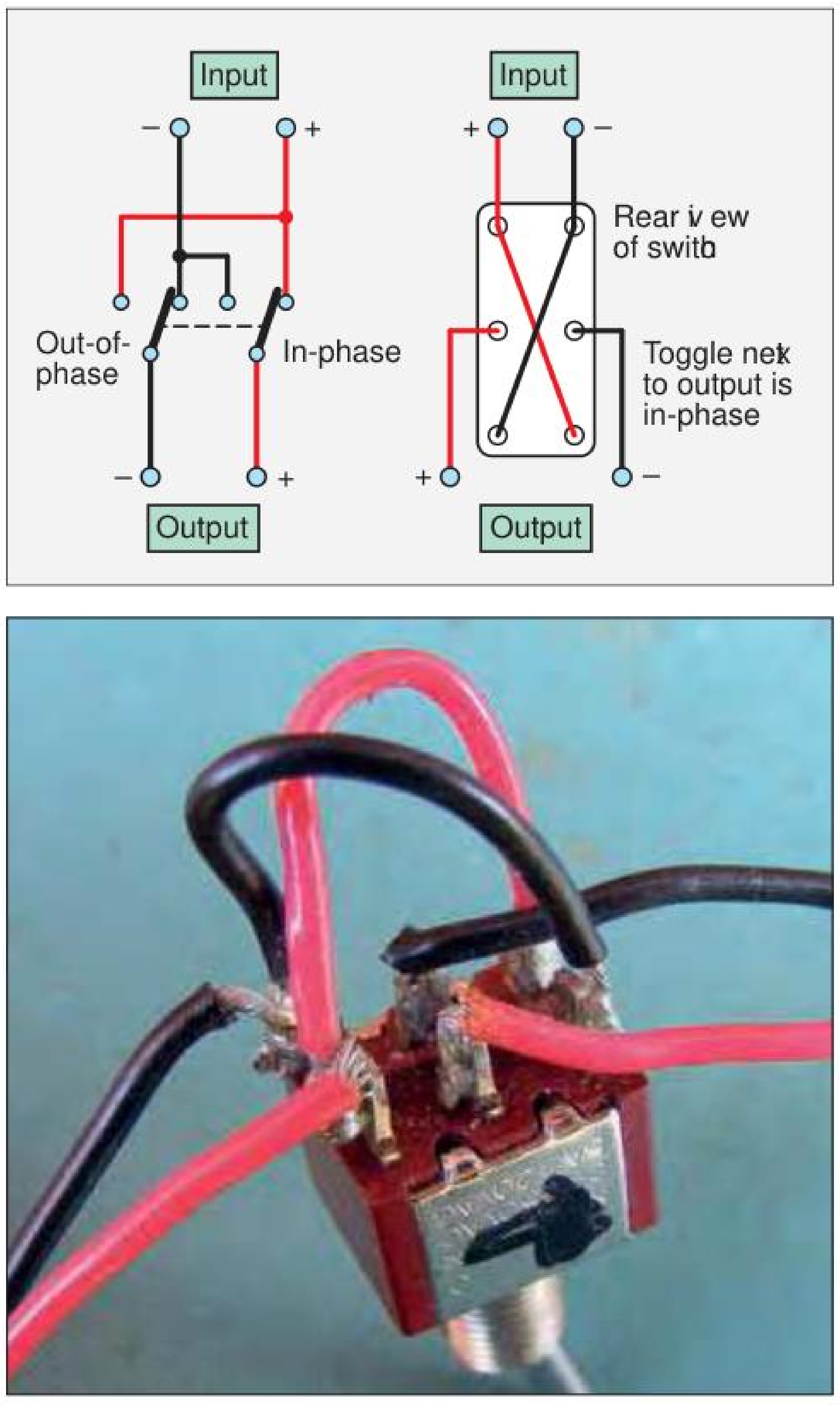


Fig.5. Try flipping the phase on the speaker with this specially wired DPDT toggle switch. Sometimes it sounds better in one position.

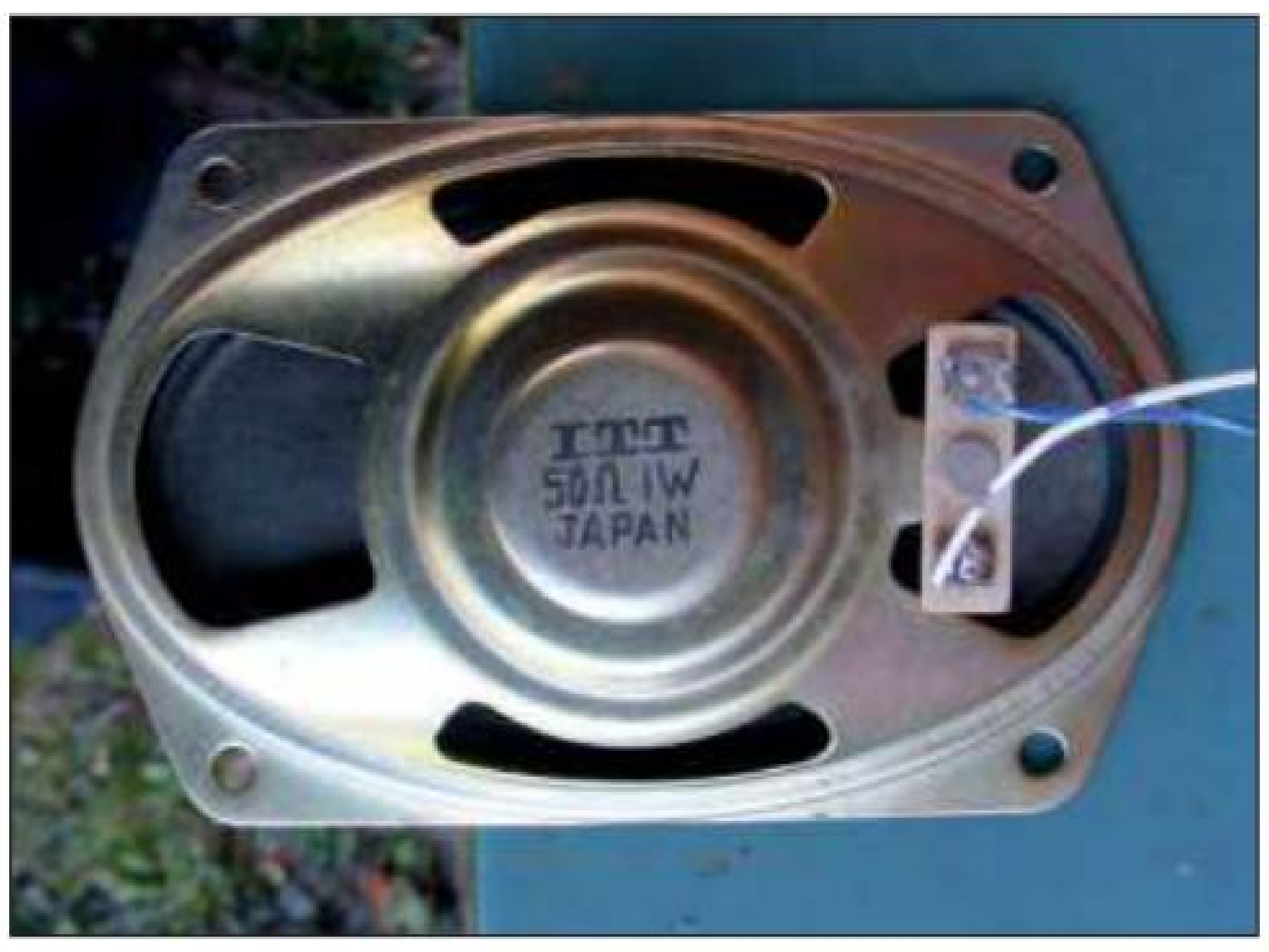


Fig.6. A suitable high-impedance speaker for the *PE Mini-organ* – note its position on the bench edge to give a baffle effect.

placed in series with the speaker to limit the current. It is placed at the output rather than the more normal input position, so that the MOSFET is always fully driven. I was surprised such a primitive arrangement worked so well. Since the resistance of the pot has to decrease as it is rotated clockwise, it has to be anti-logarithmic. Normally, a logarithmic type is used in potential divider mode where the volume increases as the resistance gets bigger going clockwise. However, here the resistance needs to decrease because the potentiometer is used a variable resistor.

The best output device to use if you want to run the instrument on low-voltage power sources, such as USB, is the Fairchild FDC634P. Unfortunately this is only available in surface-mount, but there is provision on the board for both a through-hole and SMD MOSFET. A similar MOSFET is available in a TO92 or Zetex E-line package, the ZVP2106A. This costs a bit more and has a higher turn-on voltage. It is best suited for 6-9V operation, but it will work with the USB supply, although it will give slightly reduced output. R11 is a gate-stopper resistor to prevent oscillation. R10 and R9 form the biasing network for the FET to make sure it is normally biased off. These resistors may have to be adjusted if different devices are used. D3 is a clamping diode that prevents the waveform developing an additional DC voltage across the coupling capacitor as the notes are pulsed on and off. If the diode is omitted, an interesting pulse-width modulation effect occurs as the bias changes. The diode D3 and coupling capacitor C7 could be avoided by DC coupling the output device, but then it would be difficult to bias correctly and there is always the possibility of it latching-up hard on. The speaker output is muted when a jack is inserted into the socket. A DC load on the TR2 is maintained by R12.

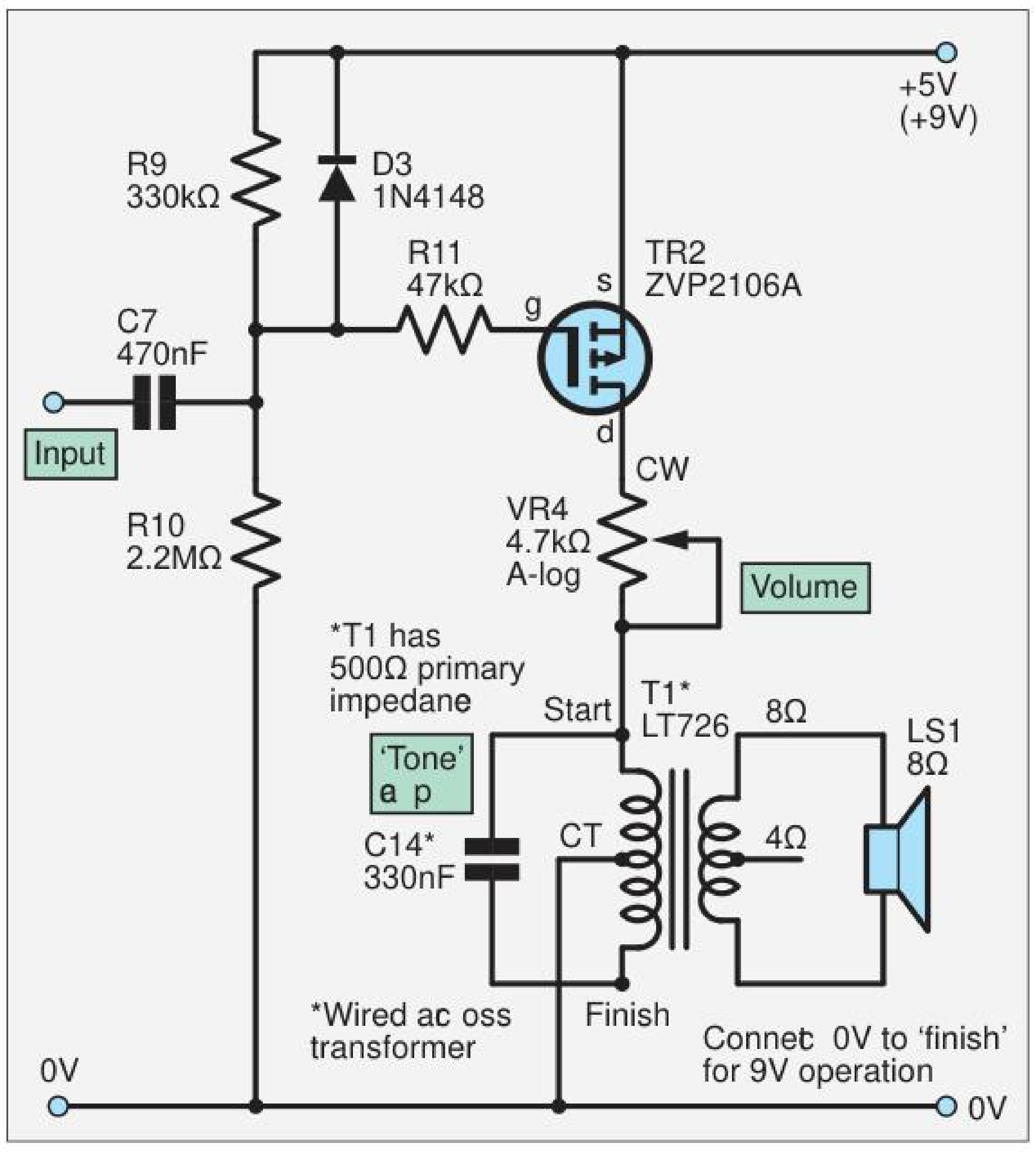


Fig.7. Adding a transformer to the *PE Mini-organ* output stage enables a standard low-impedance speaker to be used. Tuning it with a capacitor can improve the tone over direct drive.

Loudspeaker

For musical instruments, *never* use Mylar cone speaker. They're designed for alarms and have poor tone quality. Instead, use a large lightweight-paper-coned speaker, but not an 8Ω one because peak currents could reach 1.1A – not good for small batteries! High impedance speakers can be hard to obtain, so I have made provision for a supply of new old stock (NOS) 5 × 3-inch paper speakers originally made for old tube style TVs and then left in a warehouse for 20 years. For low voltages (4V to 6V) use a 50Ω speaker. For 9V, use 80Ω.

One strange observation I have made is that speakers fed with asymmetrical waveforms often sound better connected one way compared to the other. So it's worth quickly flipping the plus and minus terminals on the speaker just to check. I suspect this is because the cone motion of the speaker is also asymmetrical. A quick phase-flip switch, shown in Fig.5, is an essential bit of gear in every audio designer's tool kit. The 50Ω ITT speaker specified sounded best in phase, with the '+' on the speaker going to the '+' on the board.

A loudspeaker is an air pump and it needs a baffle or box to give good bass response. For testing, placing the speaker halfway face-down across the bench (see Fig.6), which provides an adequate degree of baffling for testing purposes.

Transformer output

If you want to use a standard 8Ω or 4Ω speakers, then an output transformer can be used to match the impedance. Even these components are now difficult to get. Luckily, Mouser offer several types from Xicon, also J Birkett's, a small electronics shop sell Eagle brand transformers (write to: J. Birkett, 25 The Strait, Lincoln LN2 1JF). There is a degree of leakage inductance with transformers, so it is possible to use this to resonate with a capacitor (C14), producing a peaking low-pass filter, which gives a 'warm' tone. This trick was often used in low-power valve amplifiers. Since transformers are still used extensively in expensive 'Neve' style audio processors, this is a low-cost way of introducing their principles to audio engineering students. Fig.7 shows the transformer circuit and Fig.8 shows a photo of the transformer. One of the interesting points of inductive/transformer loading is that very little of the power-rail voltage is lost, unlike the high impedance speaker. This means the transformer should present a load of at least 200Ω (for 5V) and 500Ω for 9V to give the same power consumption and power output as a high-impedance loudspeaker.

Next month

In *Part 2* next month we will discuss compnents, including sourcing them, and how to assemble the project.

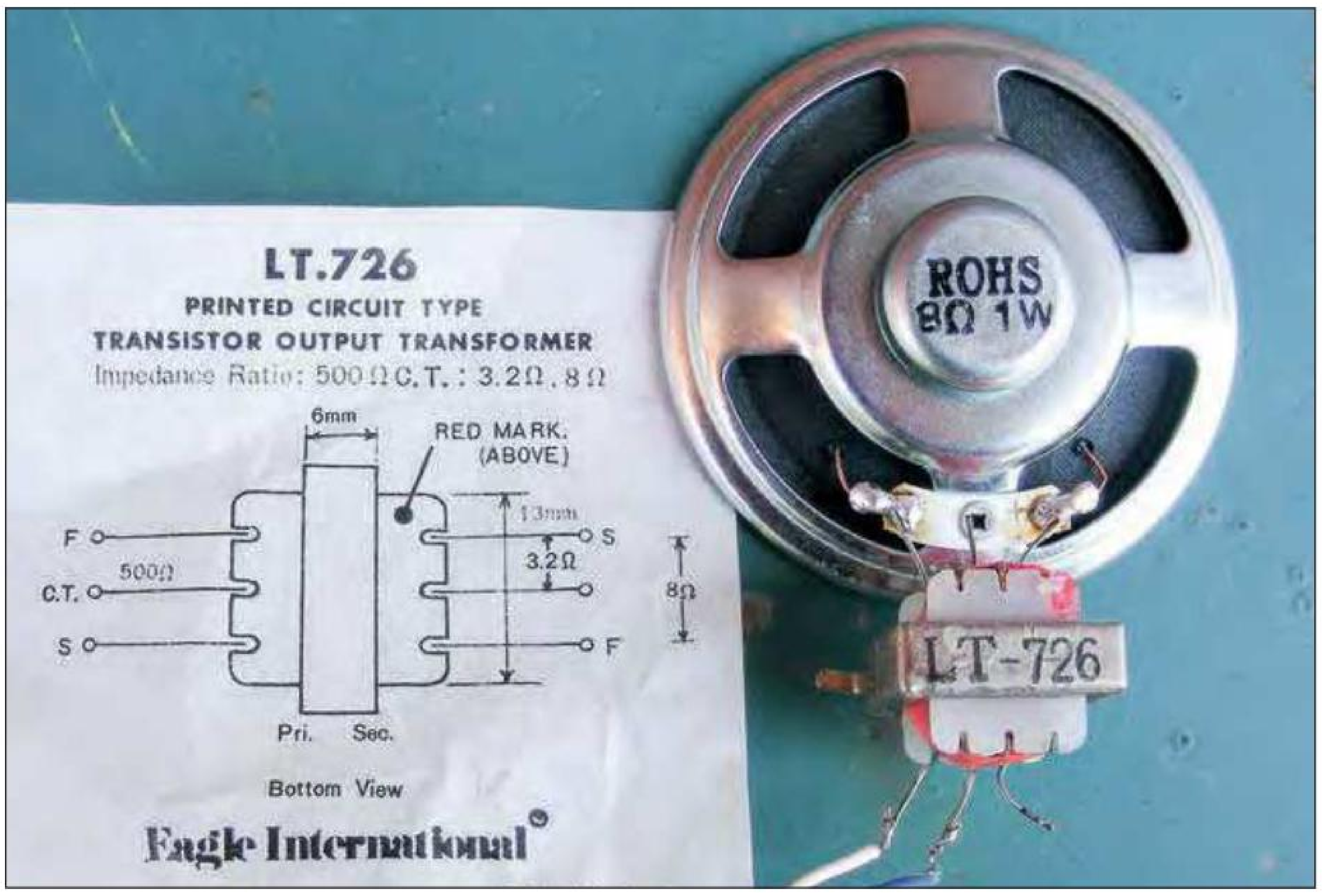


Fig.8. Output transformer for impedance matching. It's too big to mount on the board, so should be mounted in a secure way.

Max's Cool Beans

By Max the Magnificent

Home working and flashing LEDs

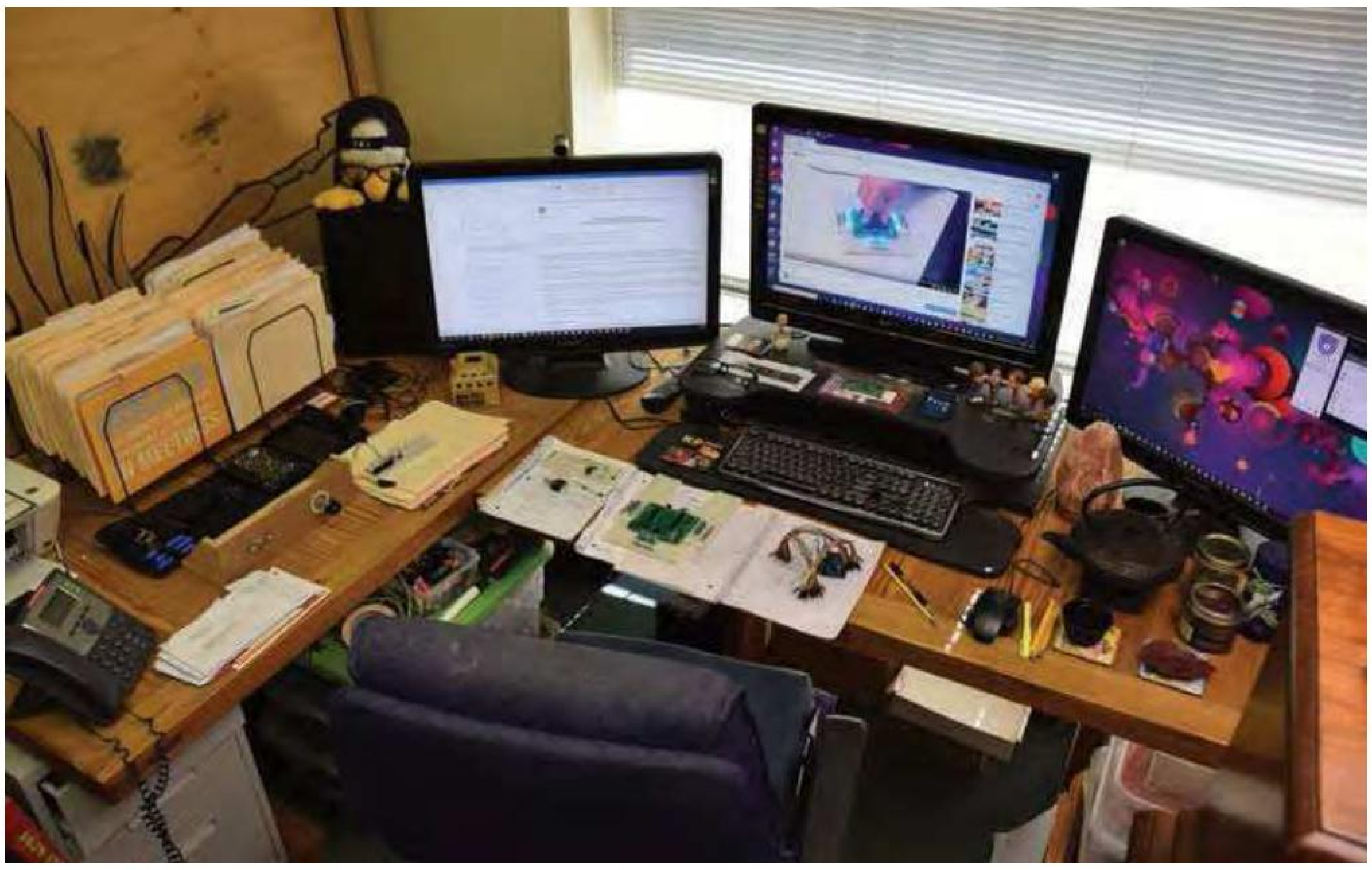


Fig 1. Welcome to the pleasure dome (my office). Note all the plastic boxes crammed with cables and components under the desk.

I don't know about you, but I'm in a bit of a tizz-woz at the moment. As you may know, although I was born and bred in Sheffield, Yorkshire, England, I currently hang my hat in Huntsville, Alabama, US (I moved here for the nightlife – that's a little Alabama joke right there).

Almost a real job

We subscribe to BritBox, so each weekend we get to binge-watch a week's episodes of Good Morning Britain (GMB). The UK was put under lock-down a couple of weeks ago at the time of this writing. We aren't under lock-down here in Alabama, although many other states are and there are rumours we might be joining them soon, but we have been advised to work from home if at all possible. Thus, I'm penning these words with numbness in my nether regions caused by sitting on a hard wooden chair at my kitchen table (the things I do for you!).

Actually, I started working from home at Maxfield Mansions a couple of weeks ago. Theoretically, as a freelance technology consultant and writer, I could work from home all the time. In practice, I rent an office in a building downtown. My office is lined with bookshelves bursting at the seams with technical books, science fiction books, and graphic novels – pretty much everything my wife (Gina the Gorgeous) deems to be incompatible with the ambience of our study at home. The office also forms a repository for my large hobby projects, which typically feature a lot of strange sounds and flashing LEDs, and which are also – inexplicably – denied pride of place in our family room.

Quite apart from anything else, getting up at 6:30am each morning, arriving at the office some time before 8:00am, and working away till 5:00, 6:00, or 7:00pm, depending on the work I have in, almost makes it seem like I have a real job.

I miss my office

Working at home isn't dreadful. I have my laptop plugged into a beautiful curved 34-inch monitor that I paid an arm-and-a-leg for about four years ago, and that you can now purchase for peanuts at local electronics stores, but such is the way of the world.

However, it has to be said that I really miss the setup I have in my office, with my tower computer driving three 28-inch monitors that form a single desktop (Fig.1). The reason the monitor in the middle is a little higher than its companions is that it sits on one of those motorised stands that can raise it so I can work standing up (I fully intend to make use of this feature… one day soon).

Stay secure and be alert

There's an old joke that goes, 'Be alert (the world needs more lerts).' I didn't say it was a good joke. I read with interest Alan Winstanley's recent *Net Work* column (*PE* April 2020), in which he discussed various aspects of Internet security, including 'The curse of cookies,' 'The rise of the Cookieless Monsters,' and 'How browsers leave fingerprints.'

In my case, I have what I consider to be a reasonably typical setup. As noted earlier, this includes a tower computer in my office and a laptop computer at home. Both are PCs running Windows 10 protected by Windows Defender augmented by Norton Antivirus. I use Outlook for my email (the app, not the browser interface), and both of my systems are synchronised via Google's G Suite, which means that any email activity (sending, receiving, deleting, moving) on one machine is immediately reflected on the other if it is currently active. Alternatively, everything is automatically synchronised when either of the systems is powered up and Outlook is launched on that system.

Similarly, all of my data files are stored in a DropBox folder, so changes made to any file (including a 'Save' while in the process of editing a file) on one of my systems are immediately propagated up into the DropBox cloud. If my other system is active, those changes are also promulgated from the DropBox cloud to the DropBox folder on that system.

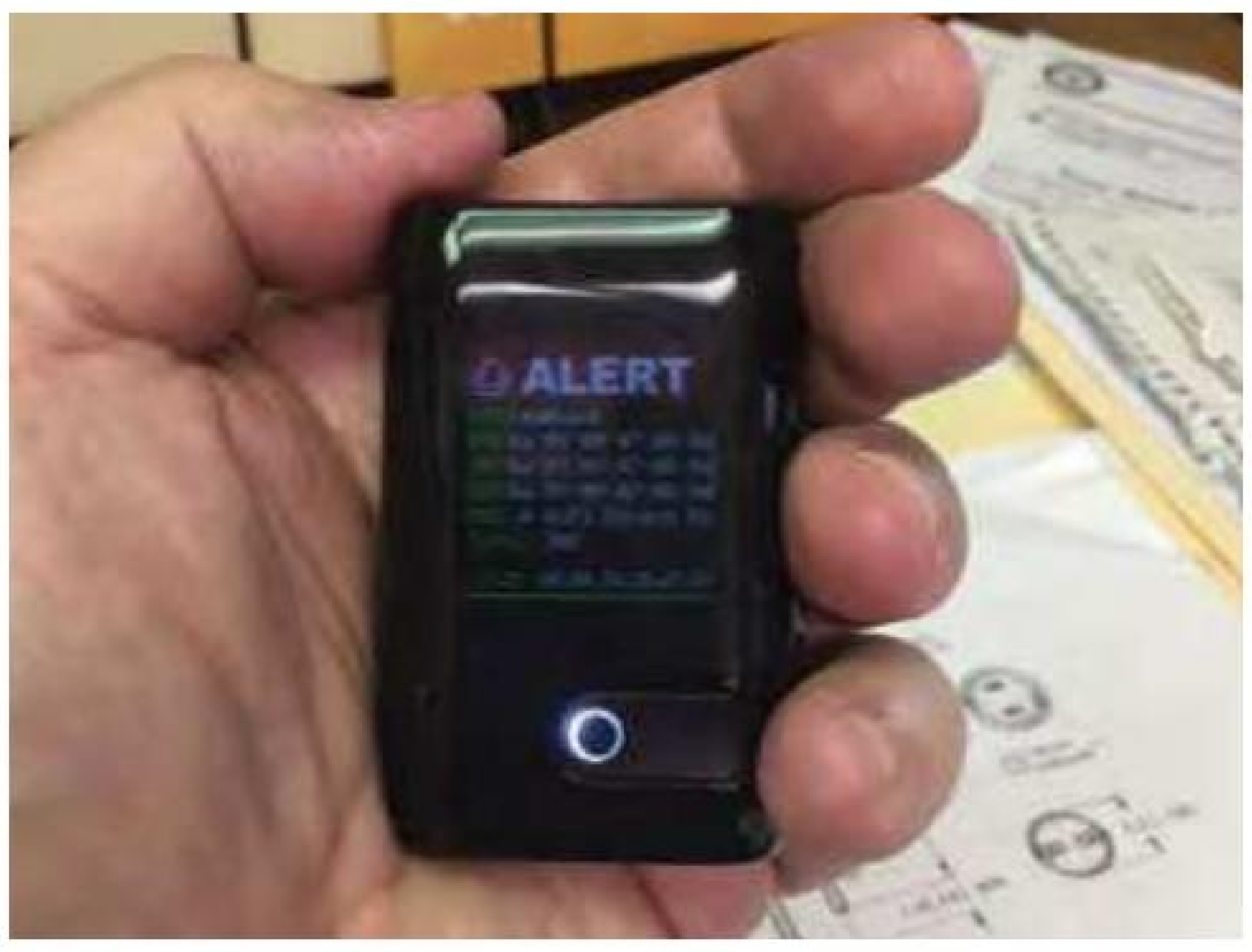


Fig 2. My Traveler identified 302 worrisome Wi-Fi networks on the 30-minute drive from my home to my office.

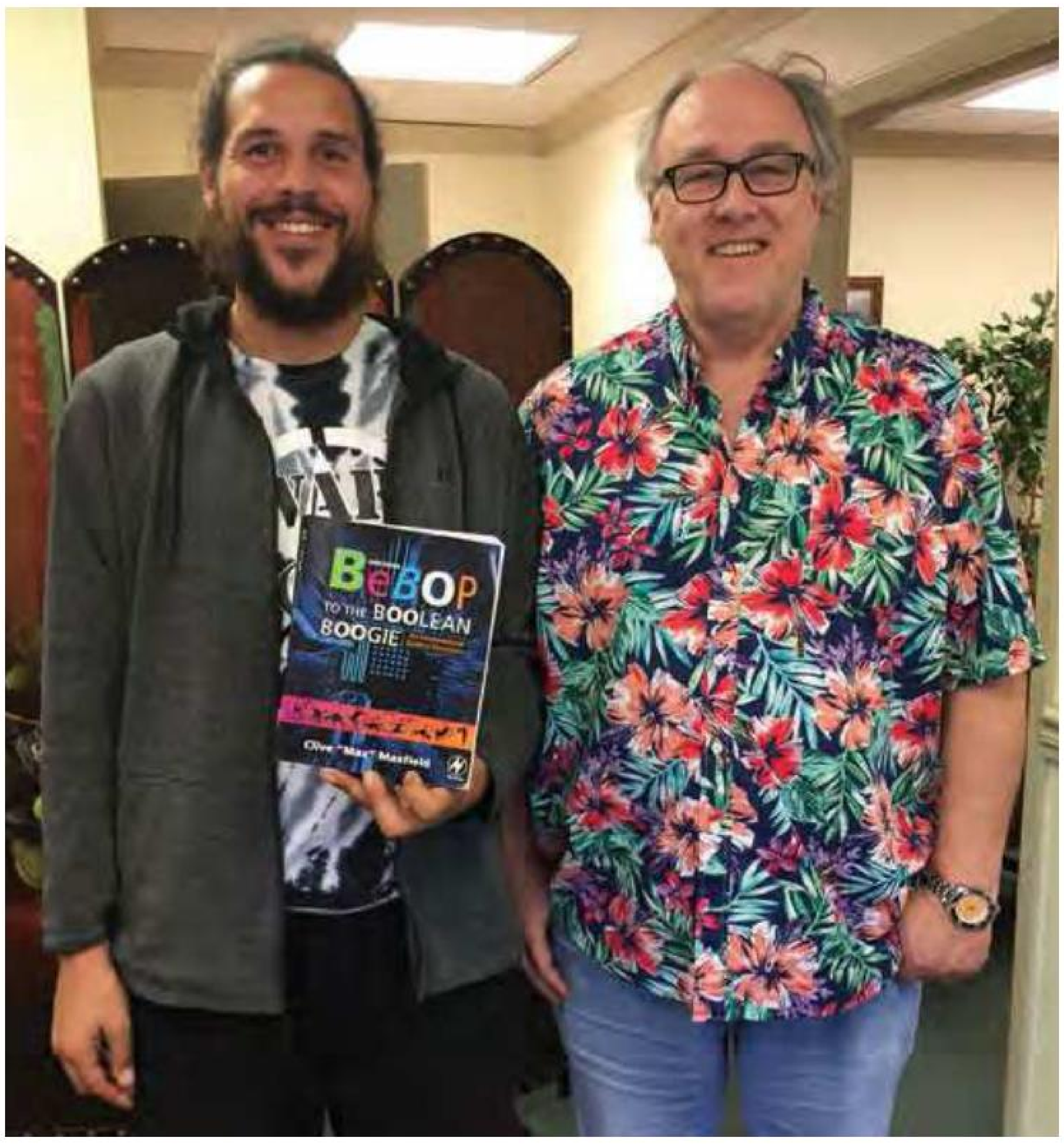


Fig 3. Goodly Juju and yours truly standing outside my office (I'm the one in the Hawaiian shirt).

Alternatively, everything is automatically synchronised when the other system is powered up.

One thing I worry about is ransomware. The idea here is that you inadvertently get some malware on your system that encrypts all your files, at which point you are held to ransom to get them back. The problem from my point of view is that any such encryption activities would be seen by DropBox as changes to my files, which would therefore be copied up into the DropBox cloud. I personally think there should be worldwide laws and rigorous enforcement for this sort of thing. When caught, the perpetrators should be hung up by their short-and-curlies and spend the rest of their lives in jail (and I say this with love).

Until this happy day is upon us, once a week I disconnect whichever computer I'm working on from the Internet, perform a full virus scan, plug in an external drive, back-up the contents of my DropBox folder, to the external drive, unplug ('air gap') the external drive, and reconnect my computer to the Internet. Of course, there's always a chance I've inadvertently backed-up a sneaky virus, but you can only do what you can do (also, DropBox has a 'Rewind' feature that would let me regress my account by up to 30 days).

Wobbly Wi-Fi

Do you use a virtual private network (VPN)? If not, why not? The problem is that when you try to do anything via the Internet, your internet service provider (ISP) can see – and potentially log – everywhere you go and everything you do. Also, if you are using an unsecured connection, nefarious players have a much easier task of monitoring your activities and gaining access to your personal information, like the names of your cats and the numbers on your credit cards.

The idea behind a VPN – like NordVPN, PureVPN, or Norton Secure VPN – is that you have a client app on your home computer. When you run this app, it establishes a secure, encrypted connection between your machine and the VPN's host servers. Now, any information that passes between your machine and your VPN's servers looks like gibberish to any observers, including your ISP, so you are 100% secure, or are you?

Well, if your computer is connected to the Internet via a wired (Ethernet) connection, then a VPN does indeed make you reasonably secure. The problem arises if you are using Wi-Fi in a café, hotel, airport… even in your home. The thing is that the lower layers (2 and 3) of the Open Systems Interconnection (OSI) model aren't covered by your VPN when you are using Wi-Fi. In turn, this means that you are susceptible to rogue access points, evil twin access points, connection hijacks, man-in-the-middle attacks, and so forth.

As one security expert told me, 'This is like having a house with a state-of-the-art alarm system, but then leaving your basement door wide open.' Happily, the guys and gals at WifiWall (**https://bit.ly/2UXP6NV**) have developed a technology they call WiFiWall Dome. Companies can employ a WifiWall Dome to monitor and secure all Wi-Fi activity on their premises. In the case of 'road warriors' who have to leave the protection of the dome, these brave lads and lasses can be provided with WifiWall Traveler units, which we can visualise as mini-domes, or bubbles.

Sad to relate, WifiWall Travelers aren't currently available for individuals, but only as part of a corporate WifiWall Dome offering. On the bright side, I happen to be in possession of my own Traveler. How? It's obvious – I'm special (my mother always used to tell me I was 'special,' and I foolishly thought she intended it as a complement).

It's a scary world out there. A couple of weeks ago, prior to becoming housebound, I powered-up my Traveler, dropped it in my pocket, and headed to my office. The Traveler constantly scans any Wi-Fi networks in its vicinity. By the time I reached my office, it had identified 302 networks as being unsecured or 'suspicious' in one way or another (Fig.2).

Of course, simply being told that there is a problem doesn't do you much good. Thus, I've informed the Traveler of the MAC addresses of my tower, my laptop, my iPhone, and my iPad. The Traveler 'sniffs' every Wi-Fi packet that passes by, paying particular attention to any packets with my name on them (ie, any of my MAC addresses). If the Traveler sees anything untoward, it will send a command to the relevant device, instructing it to immediately disconnect from the Wi-Fi, thereby protecting my device and my precious data.

But wait, there's more, because I was chatting to the folks at WifiWall just the other day. They tell me that since so many companies have employees that are currently having to work from home, they are working furiously ('nights as the days,' as the old Hebrew saying goes) on a new 'WifiWall Dome for Home' product that will allow organisations to distribute out-of-the-box Wi-Fi security solutions to each of their employees, where these solutions will include mini-WifiWall Domes and Travelers.

Simon says

Before we proceed further, I would like to give a shout-out to *PE* reader Simon Moore, who hails from Birmingham, England (there is also a city called Birmingham and a town called Sheffield in Alabama), and who will be 'chuffed' to see his name in print.

It was reading the first column in my *Flashing LED miniseries* (*PE* March 2020) that prompted Simon to purchase an Arduino Uno and a bunch of LEDs and start experimenting. Furthermore, it also prompted him to root through his old issues of the magazine to track down earlier columns on my *BADASS Display* (**https://bit.ly/pe-jun20-bad**). In fact, I just posted a column discussing Simon's recent success in using an MSGEQ7 audio spectrum analyser chip in conjunction with his Arduino Uno to flash his LEDs in response to sound (**https://bit.ly/2R9HdUu**).

Arduino for Abecedarians

Speaking of the Arduino, over the past 10 years, I've used this little rascal as a basis for teaching electronics to a number of

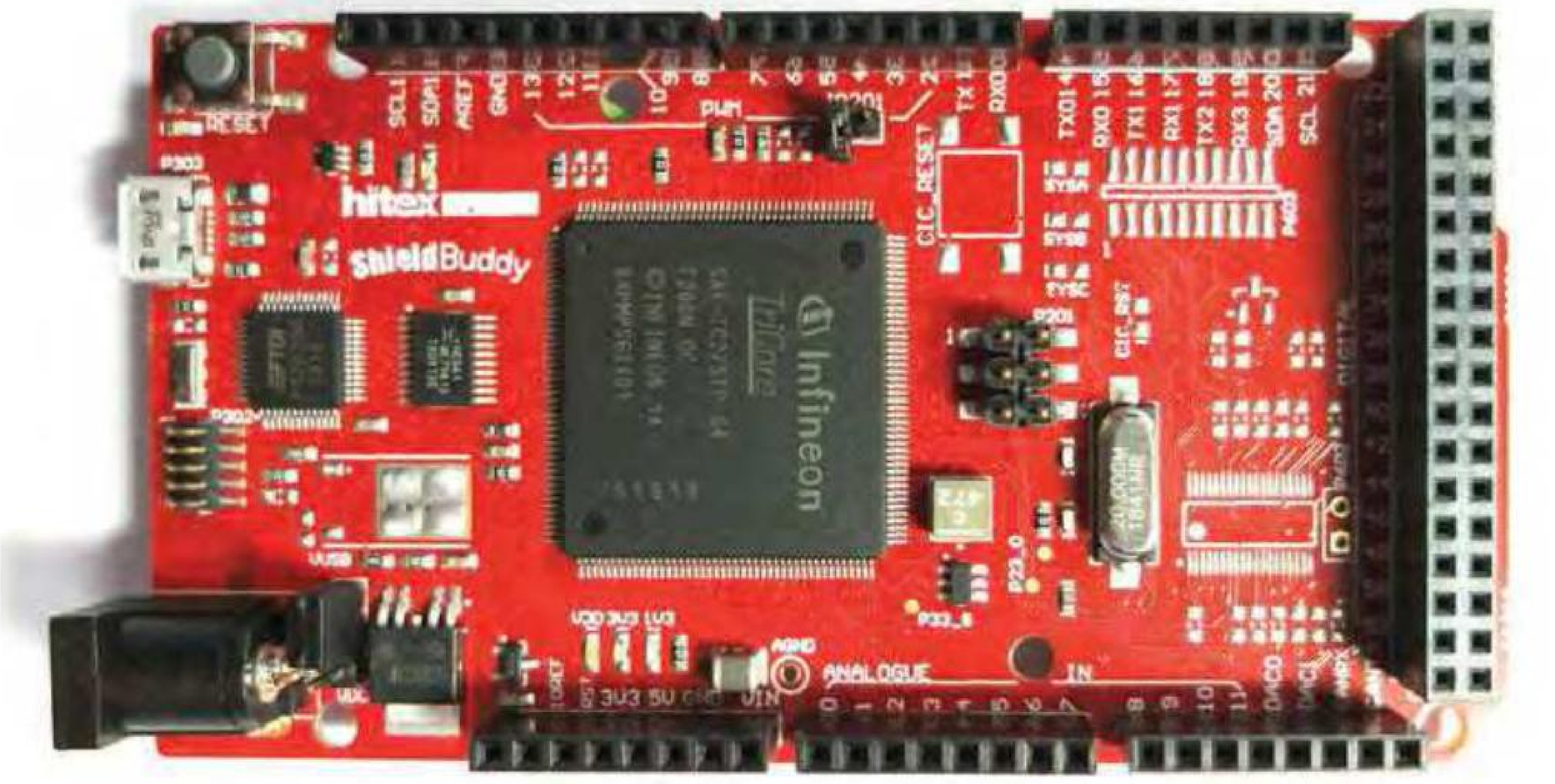


Fig.4. The ShieldBuddy has enough processing power to make your eyes water.

people, ranging from 14 to 70+ years in age. I'm currently teaching a friend called Juju (Fig.3), although I started to call him Goodly (as in 'Good Juju,' meaning 'Good Luck'), and the name seems to have stuck.

Why yes, Goodly does seem to be holding a copy of my book, *Bebop to the Boolean Boogie* (**https://amzn.to/2wOVQ8R**), I wonder where that came from. Actually, Goodly is one of the few people I know who has read this book from cover-to-cover and come back asking for more.

Goodly and his two friends own a T-shirt printing company. They are all artists and photographers and suchlike, but they know absolutely nothing about electronics and microcontrollers. This is unfortunate because they are desperately keen to introduce flashing LED effects to their T-shirt offerings. On the other hand, they know me, and if there's one thing I do know, it's how to flash an LED.

Based on working with Goodly, I decided to start a series of articles on my *Cool Beans Blog* under the umbrella name of *Arduino for Abecedarians*. I posted the first one a couple of days ago, starting with the fundamental concepts of voltage, current, and resistance (**https://bit.ly/343kKxy**). In fact, the two images in that column showing a trio of Cool Beans proudly sporting their V, I, and R T-shirts which were created by Goodly's colleague and my chum, Ronnie.

Flashing LEDs and drooling engineers – Part 4

As you may recall from *Part 1* of this miniseries, one of my hobby projects is my *Inamorata Prognostication Engine* (see this Instagram photo by **@PracticalElectronics: https://bit.ly/2UUV2Y0**).

NeoPixels are a special form of tricolour LED that we will be looking at in my next column. The reason I mention this here is that, in addition to two knife switches, eight toggle switches, ten pushbutton switches, five motorised potentiometers, six analogue meters, and a variety of sensors (temperature, barometric pressure, humidity, proximity), this little scamp has 83 NeoPixels in the upper cabinet and 116 NeoPixels in the lower cabinet. Eeek! I almost forgot (looking at the picture reminded me), there are another 155 NeoPixels powering the five monster vacuum tubes sitting on top of the engine.

For my first-pass tests, I've been powering the various subsystems (furnace, front panels, vacuum tubes) using a motley collection of Arduino Uno and Mega boards, but I've known the time is fast approaching when I'm going to need a more powerful processing solution.

Well, that solution just arrived in the form of a ShieldBuddy (**https://bit.ly/2xLZaBq**), which was created by the boffins at Hitex (**hitex.com**). The first thing you notice about the ShieldBuddy is that it has the same footprint as an Arduino Mega (Fig.4).

OK, it's time for you to sit up and pay attention because this bit is important. A standard Arduino Mega is based on a Microchip ATmega 8-bit processor running at 16MHz with 256KB of Flash memory and 8KB of RAM. By comparison, the ShieldBuddy is based on the Infineon Aurix TC275 processor. These bodacious beauties are normally only to be found in state-of-the-art embedded systems; they rarely make it out into the daylight of the hobbyist/maker world.

The TC275's 32-bit processor core runs at 200MHz and has 4MB of Flash memory and 500KB of RAM. Pause for a moment to compare these numbers with those of the Arduino Mega. To put this another way, the Arduino Mega's core manages only around sixteen 8-bit instructions per microsecond (µs). By comparison, the TC275's core has a 5ns cycle time, which means it can typically execute around 150 to 200 32-bit instructions/µs (1µs = 1000ns).

Oh wait! Did I say 'core' (singular)? Silly me. I meant to say that the TC275 boasts *three* 32-bit cores, each running at 200MHz. Furthermore, unlike the Arduino Mega, each of these cores has its own floating-point unit (FPU), which means using floating-point variables doesn't slow things down significantly.

And things just keep on getting better and better, because (a) you can program the ShieldBuddy using your regular Arduino integrated development environment (IDE), and (b) a NeoPixel library is available for the ShieldBuddy. My cup runneth over.

Diggers from Down Under

A few weeks ago, I received an email from *PE* reader, David R. Humrich, who hails from Perth, Australia. Like Simon, who we introduced earlier, David told me that he'd just finished reading *Part 1* of this miniseries, and that this had prompted him, in his own vernacular, to 'get off my bum and into the vast pile of Arduino stuff I've collected over the years.'

A few days later, David emailed again to ask if I was familiar with the Duinotech 8x5 RGB LED Shield for Arduino (**https://bit.ly/2Jz5mQ0**). I wasn't, but I have played with a somewhat similar 8x8 NeoPixel-based shield before, and I told David that an interesting little program with which he might want to experiment would be a 'worm' crawling around the display.

The idea here is that you have one pixel for the worm's 'head' and a couple more pixels for its 'body.' You light the head and the body with different colours, and you set the worm to randomly meander its way around the display. In addition to being visually appealing, this is a great little task that can facilitate learning a lot of C programming tricks. I sent David a link to a video of just such a program running on my 8x8 display (**https://bit.ly/2R5TfOn**).

Let's take the red pill

Do you remember the first Matrix movie where Neo has to choose between taking the blue pill or the red pill (**https://bit.ly/39AW2Wo**)? As Morpheus says: 'You take the blue pill – the story ends, you wake up in your bed and believe whatever you want to believe. You take the red pill – you stay in Wonderland, and I show you how deep the rabbit hole goes.'

Well, I'm afraid I opted for the red pill, because my dialogue with David has prompted me to plunge headfirst into my own rabbit hole to build a magnificent matrix based on ping pong balls illuminated by NeoPixels – something like the 'Video Wall' you can see on YouTube (**https://bit.ly/3aG1itl**).

My first pass is going to be a small 12 × 12 = 144 ping-pong prototype. At some stage in the future, I intend to construct

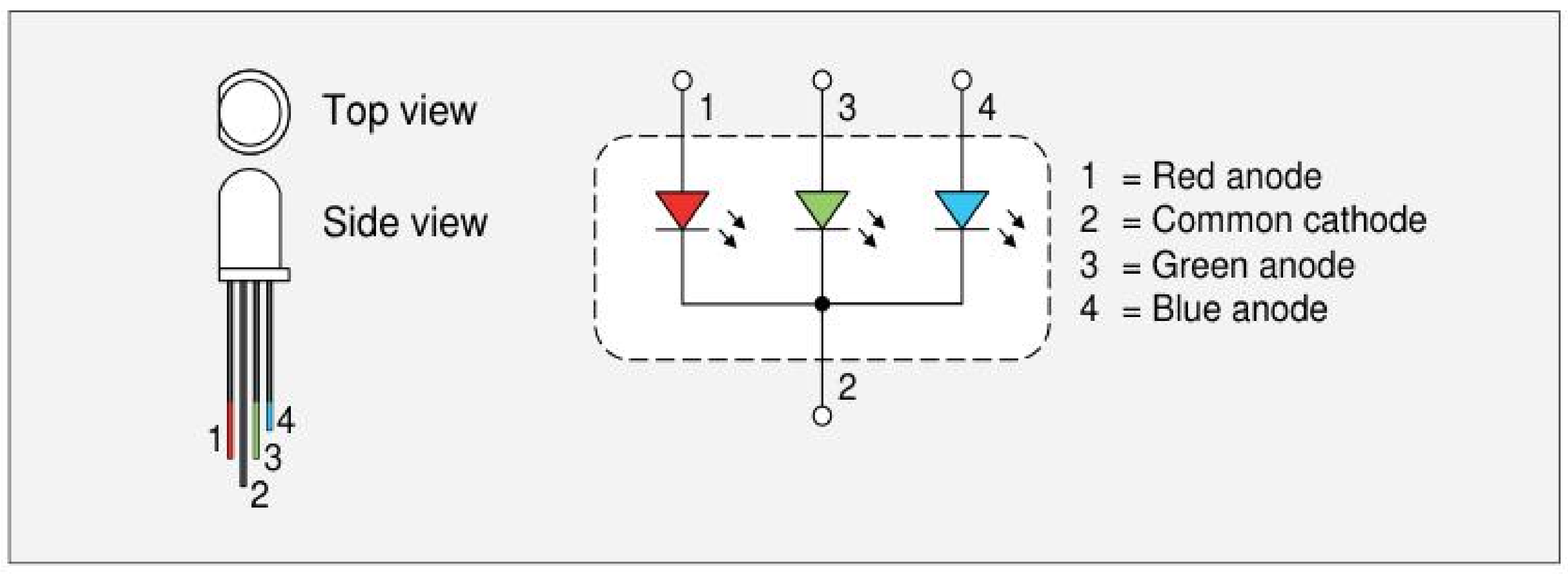


Fig.5. A regular tricolour LED.

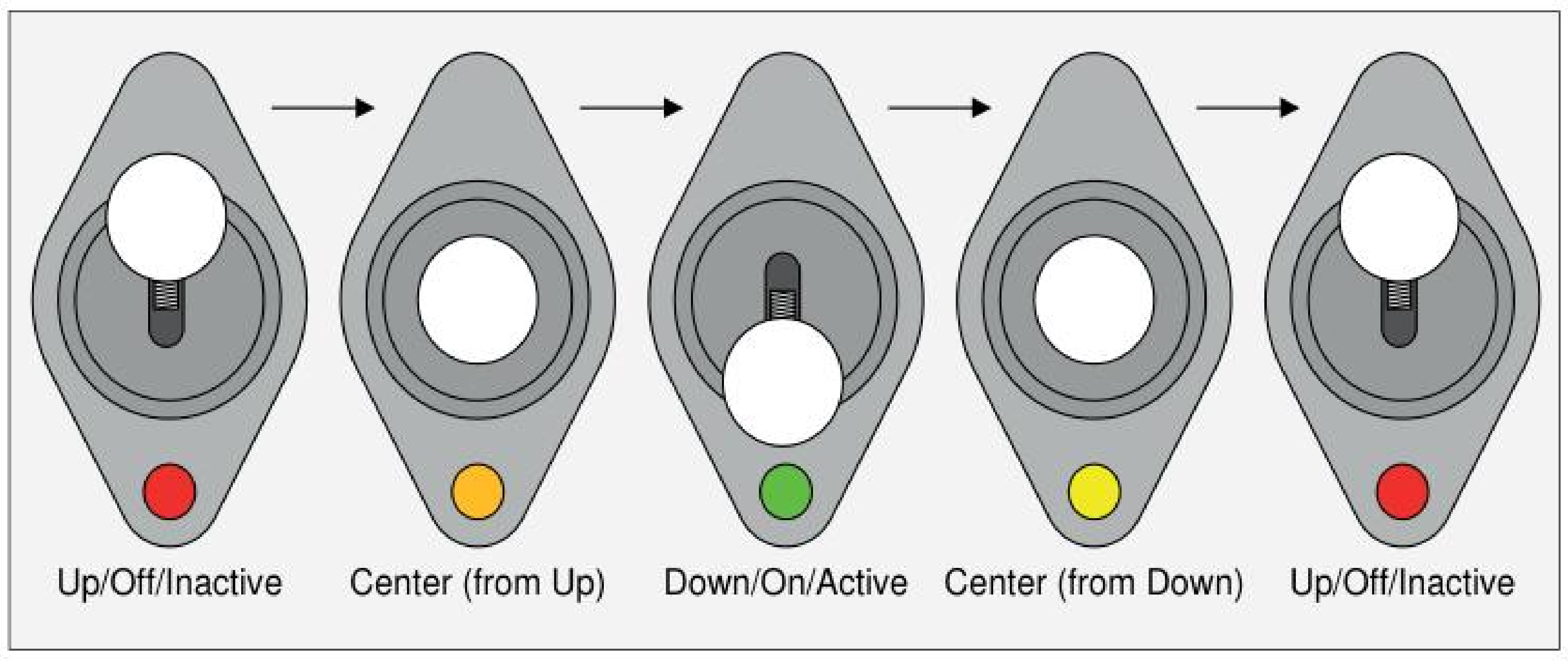


Fig.6. Using a tricolour LED with an SPCO switch and with two colours for the centre position.

a much bigger version. I just took delivery of five meters of 30-pixels-per-meter NeoPixel strip from Adafruit (**https://bit.ly/3dOa5v4**). I also received 288 ping-pong balls (I always believe in having spares) from Amazon, where they cost only $11 for a pack of 144 in the US.

These aren't game-quality balls, but they are more than good enough for what I'm going to do with them. I will, of course, be reporting further in future columns.

Over the rainbow

Did you ever see the video of Israel 'IZ' Kamakawiwo'ole singing *Somewhere Over the Rainbow* while playing the ukulele (**https://bit.ly/34cx0f**5)? In fact, it was seeing this video that prompted me to build my own ukulele, but that's a story for another day.

First, I haven't forgotten that we looked at bicolour LEDs in my previous column (*PE* May 2020) and that I still owe you a sketch (the file is **CB-Jun20-01.txt** – now available for download from the June 2020 page of the *PE* website) and a video (**https://bit.ly/2XiVli0**) relating to the 2-terminal device.

Well, the next step up the ladder is to use a tricolour component, which contains red, green, and blue LEDs (Fig.5). I'm using Chanzon 5mm RGB LEDs, which you can purchase in 100-piece packs from Amazon UK for only £5.18 (**https://amzn.to/2x1mc7l**).

According to the datasheet, the red diode has a forward voltage drop of 2.0 to 2.2V (we'll assume 2.0V), while the green and blue diodes both have forward-voltage drops of 3.0 to 3.2V (we'll assume 3.0V). Furthermore, the datasheet says that all three diodes have maximum forward current values of 20mA. From previous columns, we know that this means we'll need to use a 150Ω current-limiting resistor in series with the red diode, and 100Ω resistors for the green and blue diodes.

If we just turn our three diodes on and off, we can achieve $2^3 = 8$ different colours: red, green, blue, yellow (red + green), cyan (green + blue), magenta (red + blue), white (red + green + blue), and black (all off).

Alternatively, if we use 8-bit pulse-width modulation (PWM) to control the brightness of each diode (*PE* March 2020), this means each diode can have 256 different levels. Thus, mixing all three diodes allows us to achieve 256 × 256 × 256 = 16,777,216 different colours.

For the purposes of this column, assuming the use of a single-pole, centre-off (SPCO) switch (*PE* May 2020), we will use our tricolour LED to generate only four colours: red, green, yellow, and orange. We'll use red to indicate when the switch is Off/Inactive, green to indicate when the switch is On/Active, and either orange or yellow when the switch is in its center position to provide an indication as to its previous state (Fig.6). You can download a sketch (file **CB-Jun20-01.txt** – available on the June 2020 page of the *PE* website) and watch a video (**https://bit.ly/3b6hDYx**) to see all of this in action.

Next time

Standard tricolour LEDs can be a lot of fun, but they also have several disadvantages, not least that they each require three output pins from our microcontroller to drive them.

By comparison, the NeoPixels we will be looking at in my next column each have only four pins: 0V, 5V, Data-In, and Data-Out. Each NeoPixel contains a little controller along with three 8-bit PWMs (one each for its red, green, and blue LEDs). As we will see, we can daisy-chain these little beauties together, allowing us to control hundreds of pixels with a single pin from our microcontroller.

As always, I welcome your comments, questions, and suggestions. Until next time, be safe, wash your hands, drink cold lemonade (responsibly, and assuming you are of drinking age), eat hot bacon (or cheese) sandwiches, and wear Hawaiian shirts (Hey – it works for me).

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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Max's Cool Beans cunning coding tips and tricks

In my previous column (PE May 2020), I promised that this month we would consider how the << and >> operators perform their magic. Sad to relate, we are going to have to kick this one down the road because reader David R Humrich, who hails from Perth in Australia, emailed me with a rather interesting question relating to the use of curly brackets `{ }`.

Before we look at David's question, let's first remind ourselves that `{ }` can be used to create what is called a 'compound statement.' This is the mechanism used by the C programming language to group multiple statements into what can be thought of as a single statement.

Consider, for example, what happens when we define a function called `MyFunction ()`:

```
void MyFunction ()
{
      // Pretend this comment is a statement
      // Pretend this comment is a statement
      // Pretend this comment is a statement
}
```

When we call this function from somewhere else in the program, the computer 'sees' all of the statements in the function as forming a single logical entity.

The same thing happens if we use `{ }` along with a control statement like an `if ()`. First, let's assume that if the condition is true, we only wish to perform a single action, in which case we could write this as follows:

```
if (done == true) fred = fred + 1;
```

Now, C doesn't care how many whitespace characters we use, so:

```
      if (done == true)
            fred = fred + 1;
```

We are, of course, assuming that the variables `done` and `fred` have been declared elsewhere in the program. Now, suppose that we want to perform several actions if our condition is true. One way to do this would be as follows:

```
      if (done == true) fred = fred + 1;
      if (done == true) jane = jane - 1;
      if (done == true) bert = fred + jane;
```

In addition to looking silly, this is inefficient because we are performing the same test three times. This example calls out to us to use a compound statement as follows:

```
      if (done == true)   // Equal to above
      {
            fred = fred + 1;
            jane = jane - 1;
            bert = fred + jane;
      }
```

In this case, a compound statement is both more efficient and it makes it clearer what we are trying to achieve.

Back to David

Returning to David's question. He asked what would happen if one were to use `{ }` and hence create a standalone compound statement in the middle of a function – by 'standalone,' we mean that it's not associated with a control statement like `if ()` or `for ()`.

In fact, this is perfectly legal. If you wish, you can simply use { } to gather a group of statements together to make it clear to yourself and anyone else that you consider these statements to be related. These are often referred to as a 'block,' and using this technique may be referred to as 'block programming.'

You can also have nested `{ { } }` to whatever level you desire. But the really interesting thing is that, in addition to statements, your blocks can also contain variable declarations.

Why is this interesting? I'm glad you asked. In my previous column, we talked about global and local variables. We noted that global variables are declared outside of any function and can be seen and modified by any function. By comparison, local variables are declared inside a function and can be seen and modified only by the function in which they are declared.

We also talked about the 'scope' of a variable, which refers to the extent to which that variable can be seen. For example, if we declare a variable as part of a `for () loop`, the scope of the variable is limited to that loop (*PE*, May 2020). Well, if a variable is declared inside a block, its scope is that block; that is, it cannot be 'seen' outside of the block, even by other parts of the function in which the block resides. Consider the following 'nonsense program' example:

```
int John = 6;

void MyFunction ()
{
      int jane = 9;

      {   // First block
            int bert = jane + John
            // More stuff
      }

      {   // Second block
            int jack = jane - John;
            // More stuff
      }
}
```

Remember that I use initial uppercase and lowercase letters for my global and local variables, respectively (*PE* April 2020). So, `John` is a global variable whose scope is every function in the program, while jane is a local variable whose scope is limited to `MyFunction ()`. By comparison, the scope of `bert` is limited to the first block, while the scope of `jack` is limited to the second block; neither can be seen outside their respective blocks.

Dividing a large program into a number of smaller, well-defined functions makes it easier to test each function in isolation and reuse functions in different programs. Similarly, one advantage of using a block-based technique to limit the scope of variables is that it makes it easier to reuse those blocks in other functions and other programs.

Next Time

I'm not going to say what we'll be looking at next time because things change quickly around here (I've learned my lesson). We'll all just have to wait and see. Until then, have a good one!

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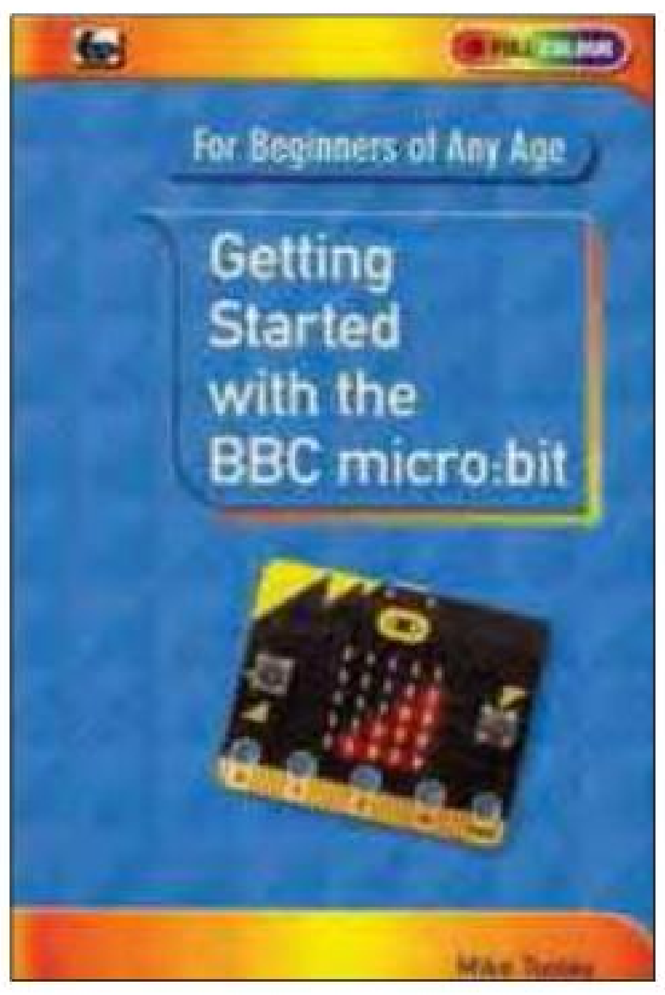

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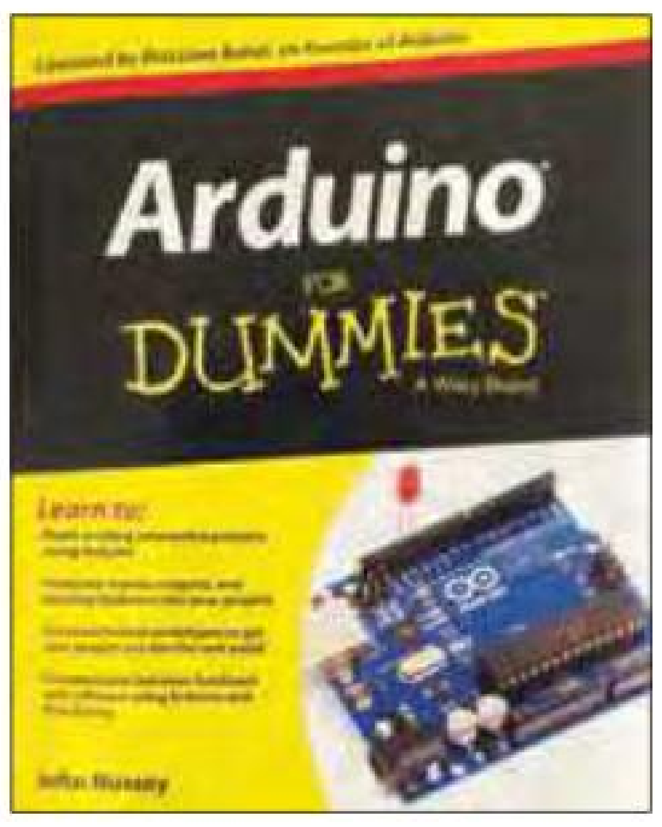

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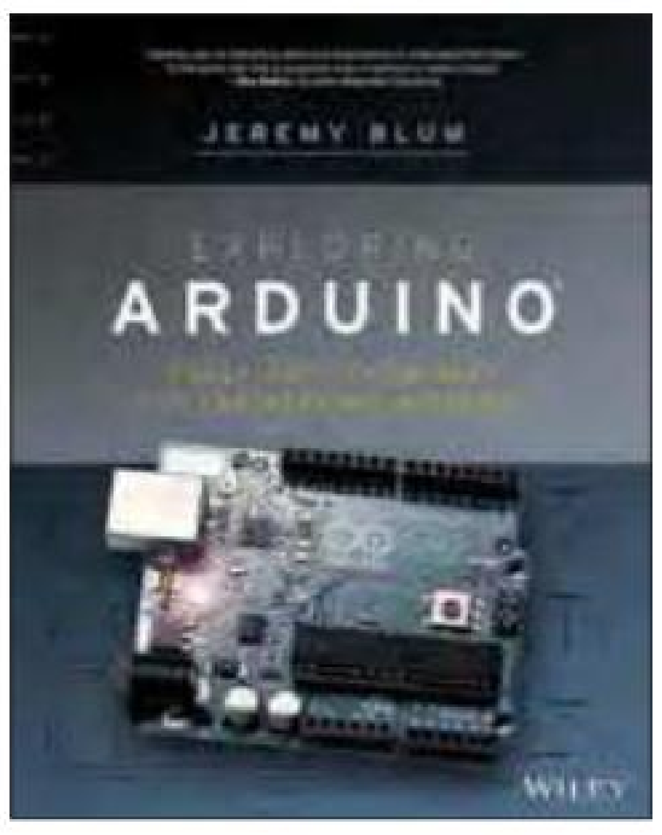

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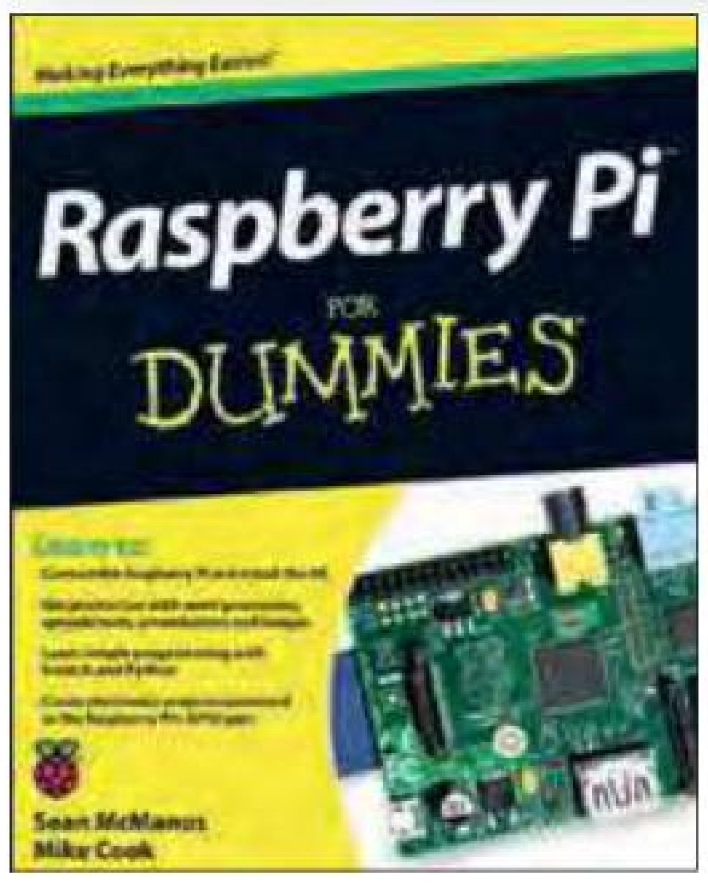

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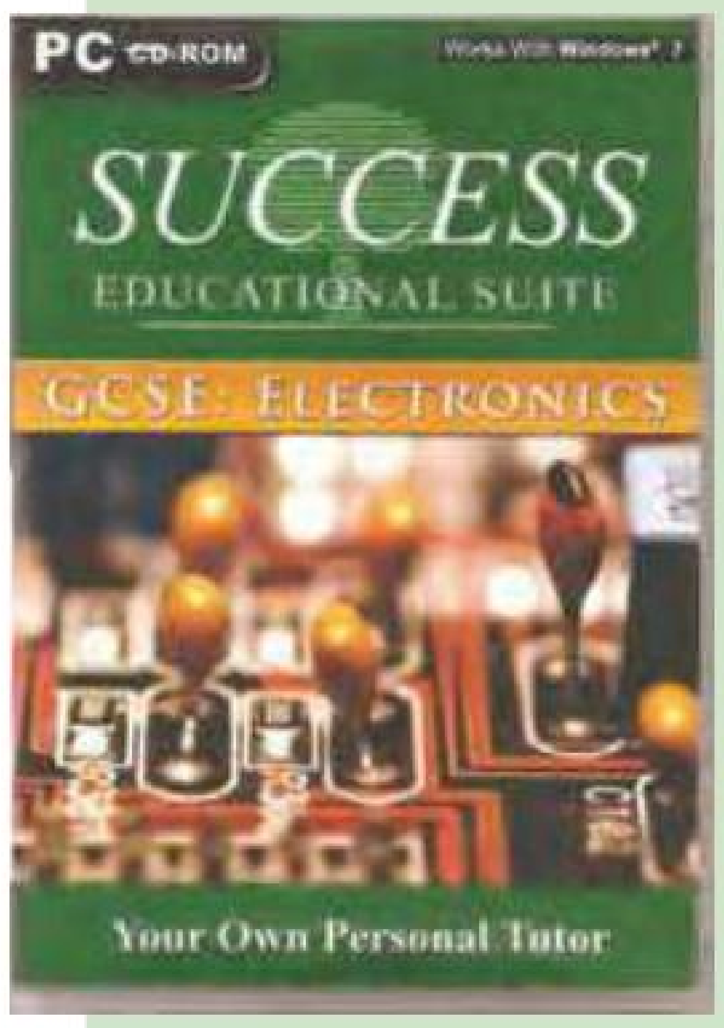

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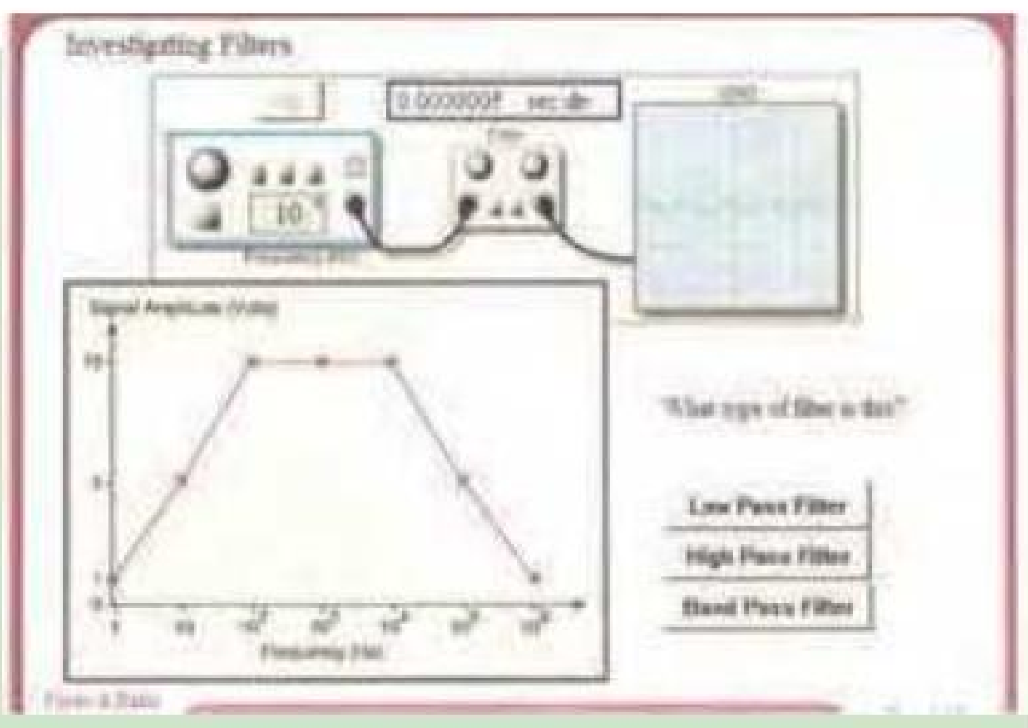

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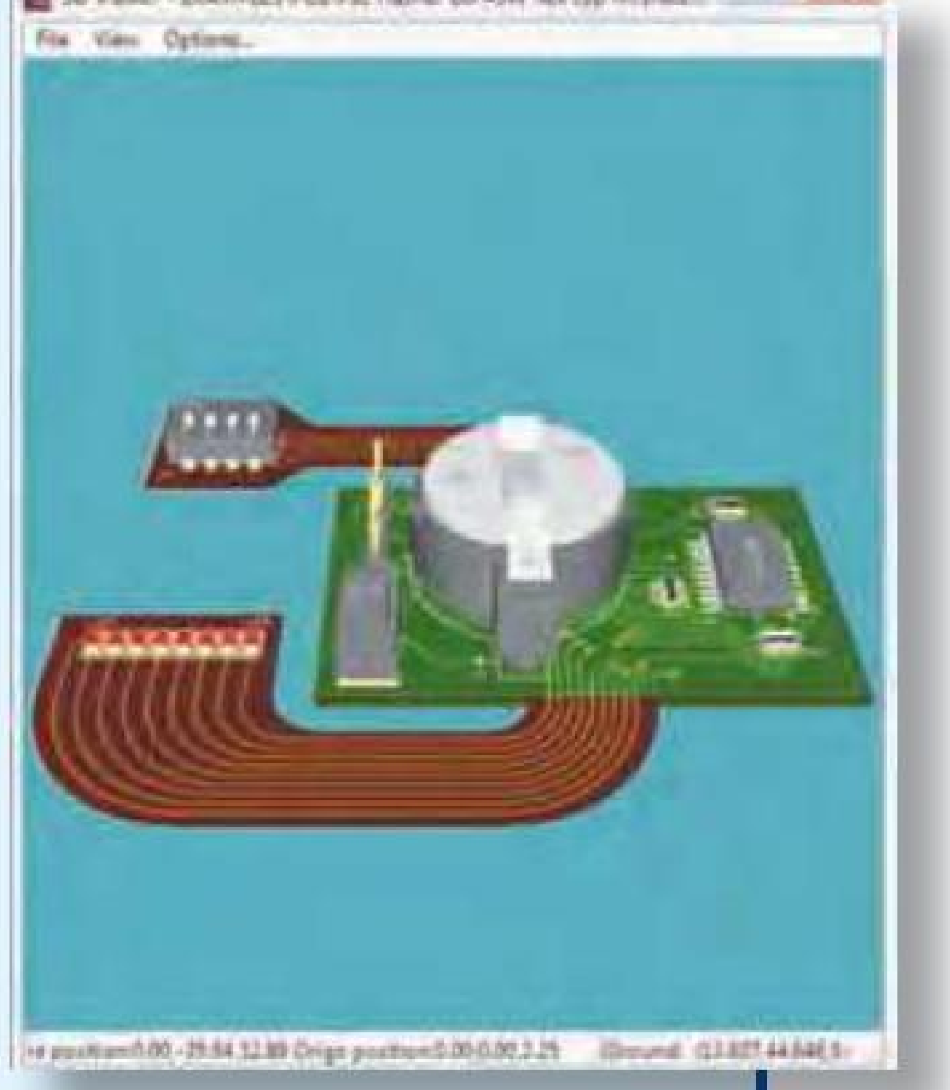

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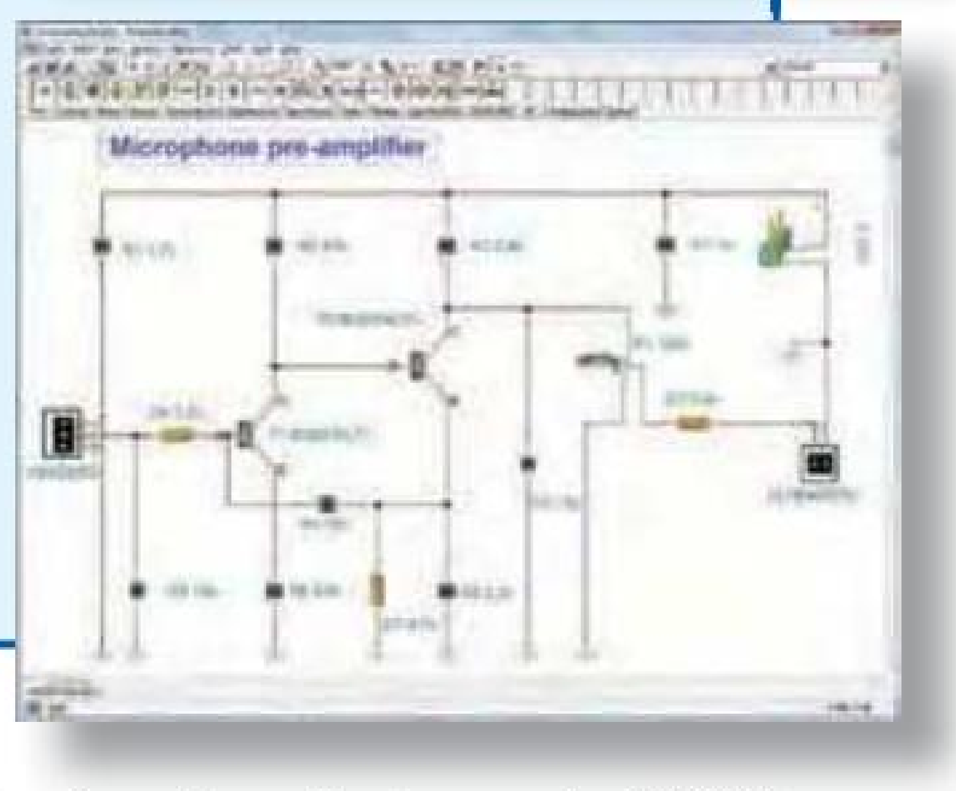

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This flexible PICmicro microcontroller programmer board and combination board allows students and professional engineers to learn how to program PICmicro microcontrollers as well as program a range of 8, 18, 28 and 40 pin devices from the 12, 16 and 18 series PICmicro ranges. For those who want to learn, choose one or all of the packages below to use with the hardware.

- Makes it easier to develop PICmicro projects
- Supports low cost Flash-programmable PICmicro devices
- Fully featured integrated displays – 16 individual LEDs, quad 7-segment display and alphanumeric LCD display
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Compatible with the E-blocks range of accessories

£159.99 including VAT and postage (worldwide)

SOFTWARE

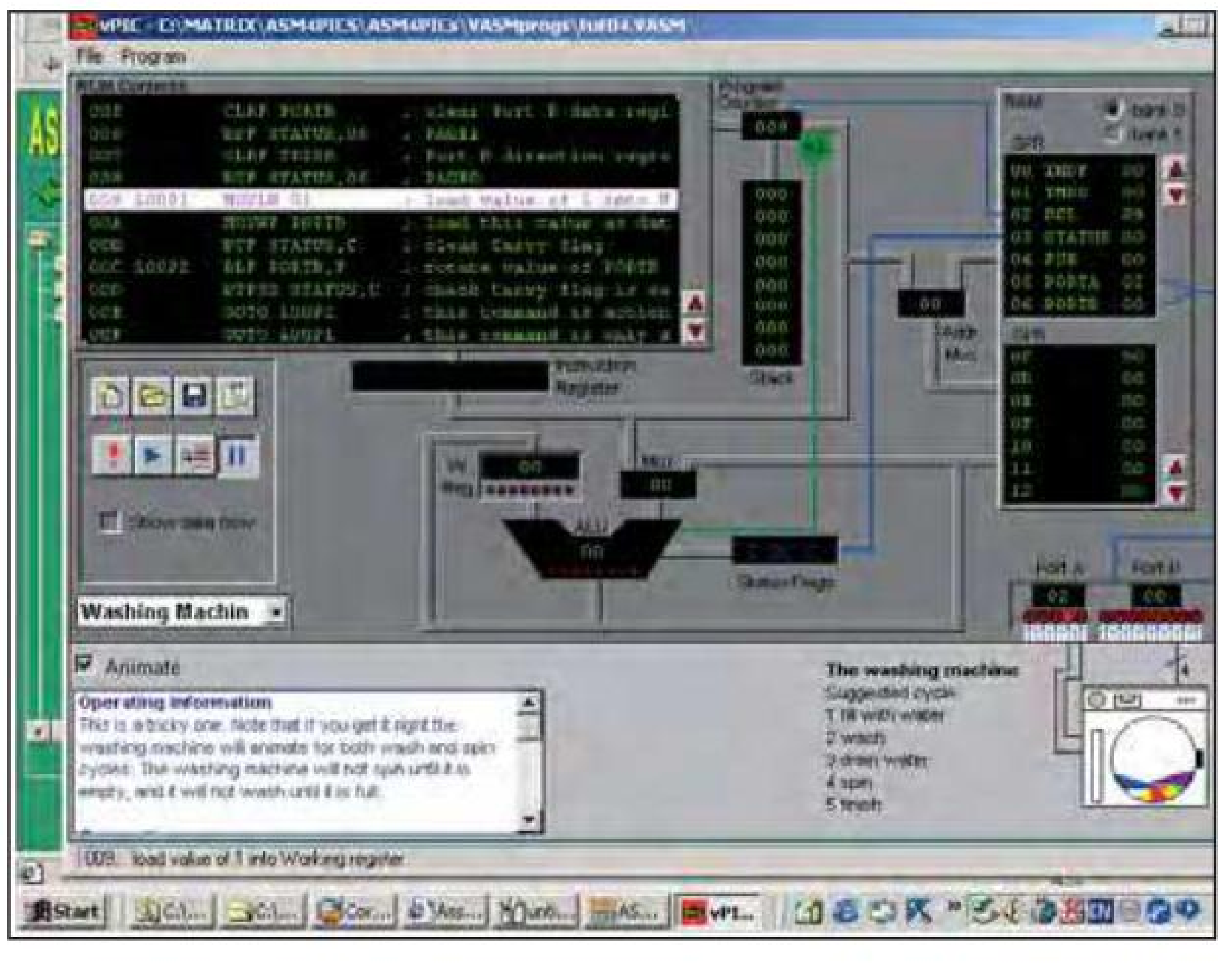
ASSEMBLY FOR PICmicro V7

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V7.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84, 16F88 and 16F877a PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

- Comprehensive instruction through 45 tutorial sections
- Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator
- Tests, exercises and projects covering a wide range of PICmicro MCU applications
- Includes MPLAB assembler
- Visual representation of a PICmicro showing architecture and functions
- Expert system for code entry helps first time users
- Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.)
- Imports MPASM files.

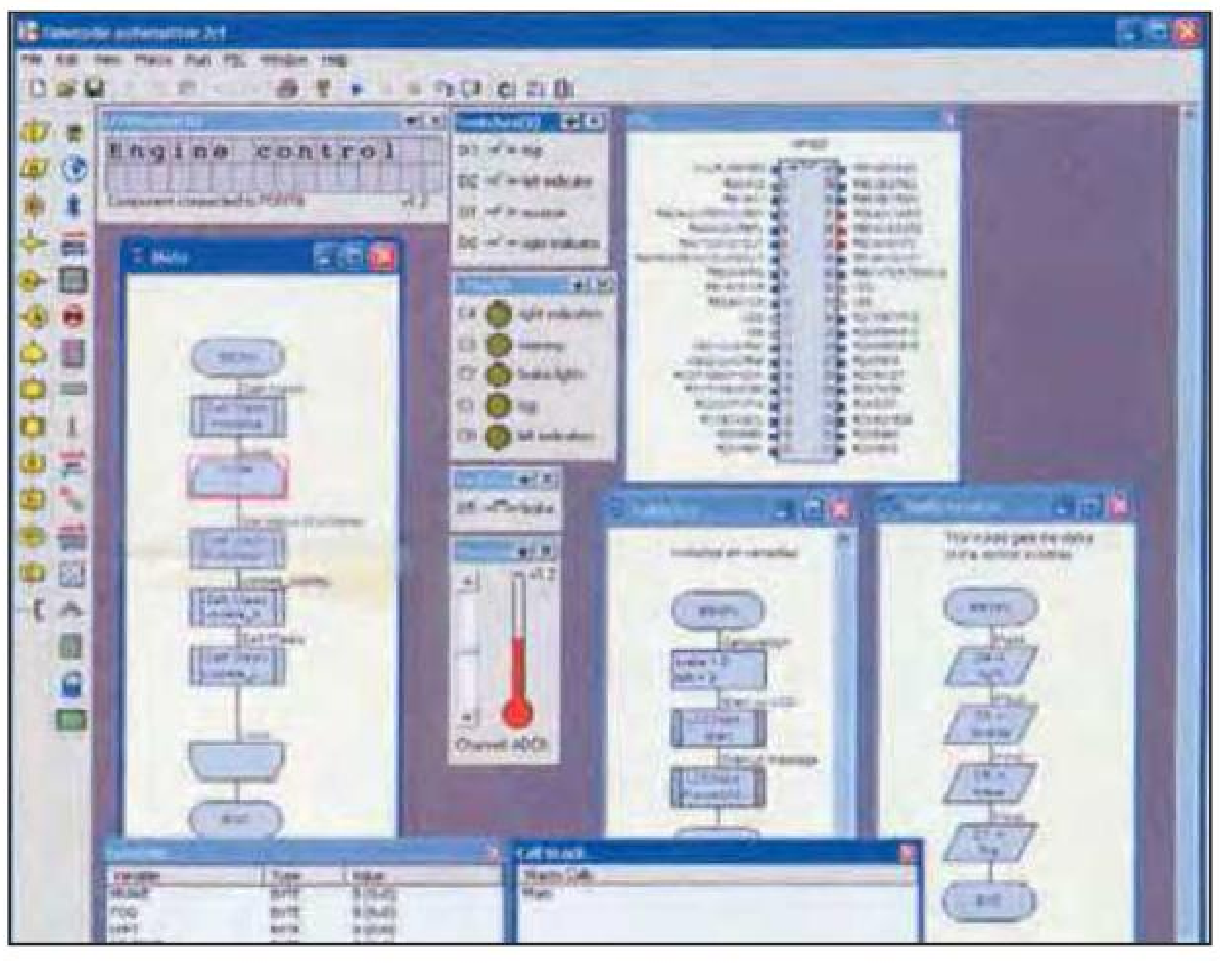


FLOWCODE FOR PICmicro V8

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces code for a wide range of devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

Please note: Due to popular demand, Flowcode is now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you.



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(Order form on next page)

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Site Licence	**£499**	**plus VAT**
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(choose PIC-8b, PIC-16b, PIC-32b, AVR/Arduino,ARM)

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Ultra-low-distortion Preamplifier pushbutton Input Selector	01111113	
433MHz Wireless Data Repeater	15004191	8.50
Bridge-mode Adaptor for Amplifier	01105191	7.95
iCEstick VGA Terminal	02103191	4.95
Analogue noise with tilt control	AO-0520-01	7.95
Audio Spectrum Analyser	PM-0520-01	8.95
APRIL 2020		
Flip-dot Display black coil board	19111181	£14.95
Flip-dot Display black pixels	19111182	
Flip-dot Display black frame	19111183	
Flip-dot Display green driver board	19111184	
MARCH 2020		
Diode Curve Plotter	04112181	£10.95
Steam Train Whistle / Diesel Horn Sound Generator	09106181	£8.50
Universal Passive Crossover (one off)	UPC0320	£12.50
Crossover component set for Wavecor speaker (one off)	WAVXO	(see website)
FEBRUARY 2020		
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DSP Active Crossover (DAC) ×2	01106192	
DSP Active Crossover (CPU)	01106193	
DSP Active Crossover (Power/routing)	01106194	
DSP Active Crossover (Front panel)	01106195	
DSP Active Crossover (LCD)	01106196	
JANUARY 2020		
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Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

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Next Month – in the July issue

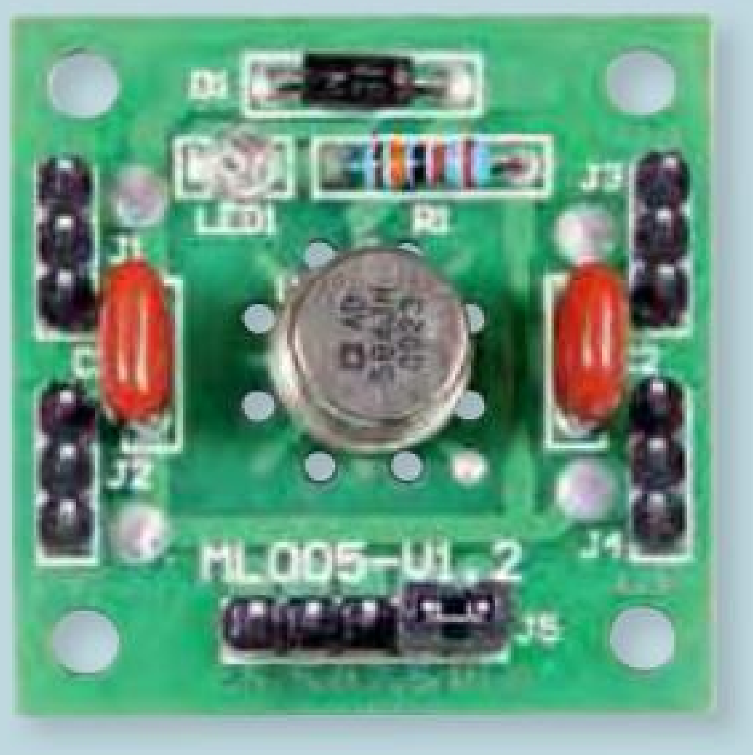
ON: 13.4V
OFF: 12.6V
MAIN
AUX
DUAL 12V BATTERY ISOLATOR

High Current Solid State 12V Battery Isolator
This project connects an auxiliary battery to the main vehicle battery/alternator while the engine is running, charging that extra battery. But it disconnects it once the engine shuts down. It's cheap, easy to build and very robust – ideal for RVs, campers, off-road vehicles and boats.

AD584 Precision Voltage References
Three low-cost precision voltage reference modules based on the AD584 IC from Analog Devices.

Speech Synthesiser with the Raspberry Pi
Most electronic devices communicate with us via blinking lights. But humans use speech to communicate virtually any concept easily and clearly. So wouldn't it be better if your electronic gadgets spoke to you? Now you can make them do just that, with a low-cost Raspberry Pi.

AM/FM/CW Scanning HF/VHF RF Signal Generator – Part 2
This is an ideal entry-level test instrument for anyone into radio: capable, yet low in cost and quite easy to build. None of the parts are too hard to come by, either. Next month, we'll get into building it, getting it up and running – and explain how to use it.



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PEAK electronic design ltd
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Slope R=53Ω
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Zener Voltage
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on - test
scroll - off
warning: not for in-circuit

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LCR and impedance meter
PEAK
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L=701.1µH 15kHz
LCR45
on - menu
enter - off
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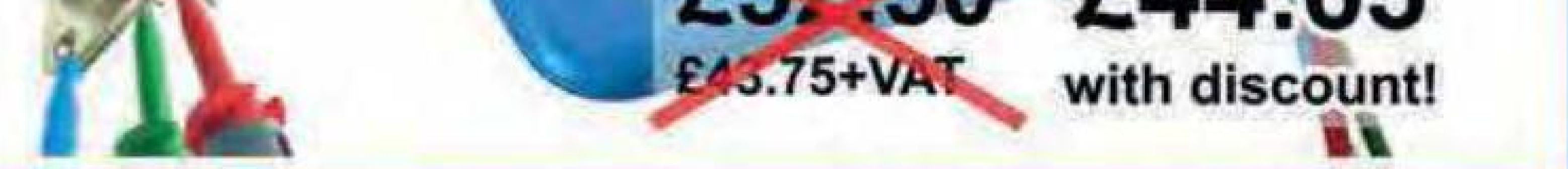
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with automatic discharge function
on - test
off

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